Translational approaches to studying reward-based purposive behaviours

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Declaration

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Kate S. Doran

Date: / /

Preface

The research contained in this thesis was conducted in the addiction unit of the human psychopharmacology laboratory and the ancillary building of University of Sussex. It was funded by a University of Sussex graduate teaching assistantship. All work detailed in this thesis was carried out by Kate S. Doran, with additional support in the collection of data contained in chapter 3, sign-tracking and goal-tracking in rats, from a masters project student Sheena Potretzke and experiment 3 in chapter 4, sign-tracking and goal-tracking in humans, from an undergraduate student, Stephanie Collins. The eye-tracking programs were written by Dr. Samuel Hutton.

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Finally, thank you to all my family, especially Mum, Dad, Una, Owen, Jean and Paul. You have been tremendous in your unerring support and kindness. Thank you for putting up with the tearfulness, taking the many phone calls and for helping me consume large quantities of wine. I love you more than I can say.

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Summary

Within classical economics, an agent is deemed "rational" if their preferences are both consistent and maximize utility of positive, subjective experience. Violations from this norm may occur as a result of utility devaluation (proceeding from risk or delay) or when an imbalance occurs between 'liking' and 'wanting'.

The current studies investigate how changes in reward-contingencies, delay before reward receipt, and reinforcer devaluation contribute to such utility-based decision-making in human and rodent models. I examined the effects of devaluation through pre-exposure and outcome-contingency on the development and maintenance of sign- and goal-tracking responses in rats (chapter three) and humans (chapter four). Chapter four presents a novel, translational, eye-tracking procedure and correlates of such behaviour, including trait-impulsivity and discounting performance.

In chapter five I presented probability- and temporal discounting using a mouse model, exploring the consequences of satiety-based devaluation, and changes in outcome-contingencies- and delays. In Chapter six I presented the same factors in a human sample using a novel laboratory-based procedure and sought to explore the impact of trait and state impulsivity and correlates of rapid discounting.

Finally, in chapter seven I considered the relationship between trait impulsivity, alcohol use, smoking and discounting behaviour using a more conventional online questionnaire.
The results represent some of the first to present probability discounting using a mouse model and characterisation of reliable sign- and goal-tracking performance in humans. The results of the latter studies broadly support previous findings in rats showing that lowered reward contingency diminishes goal-oriented, but enhances sign-oriented, responding. Chapter six establishes a

human equivalent to rodent discounting paradigms through implicit learning that will allow future controlled studies in humans. Finally, chapter seven presents evidence for an association between delay discounting and trait impulsivity.

The results of these studies support the assertion that irrational decision-making arises, in part, from changes in reward utility as a function of delay, probability, devaluation and individual differences. Furthermore the translational-homologous models presented allow for future biopsychological research into mechanisms underlying such behaviours.

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List of abbreviations:

AUQ	Alcohol use Questionnaire
BIS-11	Barratt Impulsivity Scale-11
CR	Conditioned Response
CS	Conditioned stimulus
DA	Dopamine
DD	Delay Discounting
DUQ	Drug use Questionnaire
FR	Fixed ratio
EDT	Experinetial Discounting Task
GT	Goal-Tracker
HE	Head entry (into magazine)
I	Intermediate
ITI	inter-trial interval
LP	Lever Press
NA	Nucleus Accumbens
PCA	Pavlovian Conditioned Approach
PCG	Pavlovian Conditioned Gaze
PD	Probability Discounting
PIT	Pavlovian-Instrumental-Transfer (PIT)
PRE-CS HE	Head entry (into magazine) in 10 seconds prior to lever insertion
RI	Random interval
SRB	Serial response box
SDDCT	Sussex delay-discounting computer task
SPDCT	Sussex probability-discounting computer task
ST	Sign-Tracker
US	Unconditioned stimulus

1. General Introduction

1.1: The Rational

Within neoclassical economics, rational decisions maximize rewards and minimize unpleasant experience. This was described by Bentham (1789) in terms of the opposing "sovereign masters" of pleasure and pain; referring to hedonic, subjective experience which he termed *Utility* (Kahneman, Wakker & Sarin, 1997).

If utility is the common currency of the brain, which allows it to make decisions on a cognitive level (Shizgal, 1997), it can be separated into both positive and negative. The focus of this thesis is the former. Positive utility can be described in terms of *experienced, predicted, remembered* and *decision utilities* (Kahneman, Wakker & Sarin, 1997). Where the hedonic, affective and subjective experience of a reward, which is sensitive to the influence of one's internal state, is experienced utility (Berridge & O'Doherty, 2014). Remembered utility refers to an active reconstruction of the experienced utility, not just a memory (Berridge & Alridge, 2008). Predicted utility is heavily influenced by the former and extrapolated from it but reflects learning; as associations become learnt, an expectation is reached about the relationship between cue and outcome. Predicted utility has, therefore, been suggested to be a "Pavlovian prediction of reward" (Berridge & O'Doherty, 2014) so, while not contributing to decision utility, is an associative expectation of how liked a future reward will be (Berridge & Alridge, 2008). Finally, there is decision utility which is the most complex to define; Berridge and Alridge (2008) describe it as the "essence of an actual decision" (p.622), whereas Tom, Fox, Trepel and Poldrack (2007) refer to it as the representation of potential losses to gains and Kahneman and Thaler (2006) simply as "wantability". Decision utility is the judgement, considering factors such as probability, of the potential value of the outcome at the point of making a decision (Berridge & Alridge, 2008). "Good" decisions, therefore, represent instances where experienced reward utility is maximized (Ainslie, 2012). This is the basis for *rational choice theory,* which predicts that the effect of delay on present value is constant over time, therefore, the utility of a reward can be plotted against the delay until reward receipt and produce an exponential curve; modelled by the following equation:

$$\text{Present value} = \text{value}_0 \times \delta^{\text{Delay}}$$

Equation 1.

Wherein, $value_0$ refers to the value of the reward when it is available immediately, and δ refers to 1- the discounting function (Ainslie, 2010).This means that, according to rational choice theory, an agent is deemed "rational" if their preferences are internally consistent and their resources are allocated in such a way as to maximize utility over time. Figure 1.1 depicts this graphically, if we were to present an individual with a choice of two rewards at T_0, between a small reward (the blue bar) and a large reward (the red bar), then the "chooser" would always select the larger reward.

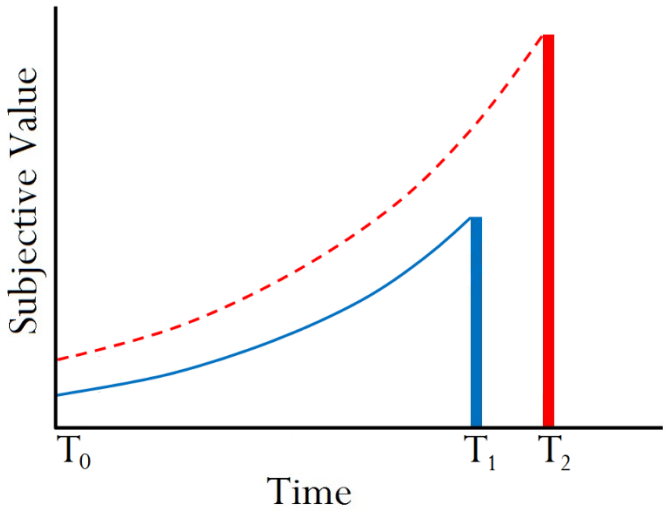


Figure 1.1 shows the reward preference, where the bars represent the objective value of the rewards, for the larger-later reward (red bar) over the smaller-sooner reward (blue bar) if rewards are discounted exponentially over time.

On this basis, decisions either across time or probability are relatively straightforward and the optimum strategy is to attempt to calculate the outcome with the highest *expected value* and select according to this criterion. However, such a method of decision making could lead to absurd selections as modelled by the rice and chess tale from Ferdowsi's (c.977-1010CE) Shahnameh; more commonly known as the St. Petersburg paradox (Bernoulli, 1738 as cited in Colman, 2013). The basis of the paradox is simple: a coin is tossed, if it lands on heads the player is paid one rouble and the game ends, if it lands on tails it is thrown again. If the coin lands on heads on the second toss, the player receives two roubles and the game ends, if it lands on tails the coin is thrown again and so on until the player wins. The final question of the paradox is how much should a person pay in order to play the game? According to rational choice theory, one should play only if the price of entry is lower than the expected value. However, should the player continue to "lose", the series of possible rewards is infinite; which means the price of entry is

always lower than the predicted utility. Therefore, it would not be an *irrational* response to offer one's lifesavings in order for the chance for winning a sum infinitely larger, despite the fact that, on the very first throw, one might reduce one's entire life savings to a single rouble (Colman, 2013).

With his description of the St. Petersburg paradox, Bernoulli (1738) described, what later came to be known as, the *law of diminishing marginal utility* which states that the value of money is not objectively set, rather it is influenced by the money one already possesses; £100 is not very much money to a man who won a million in the lottery, but the day before the prize-draw it might have been. Where Bernoulli's theory fell short, however, was the assertion that the functional relation between utility and money was logarithmic, with an increase in either leading to a proportional increase in the other. The arbitrary nature with which Bernoulli attributed a logarithmic function to this relationship was called into question; it remained unclear why the relationship should be ubiquitous across individuals and contexts. A further shortcoming lay in that Bernoulli's model proposed no method of calculating utilities if the reward was not monetary. A theory that more successfully bridged the gap between preference and choice was proposed by von Neumann and Morgenstern (1944 as cited in von Neumann & Morgenstern, 2007). Where Bernoulli had focussed his utility function on personal wealth, von Neumann and Morgenstern based theirs on preference or indifference, which were converted into utilities. This theory was called *principle of expected utility maximization* and allowed for more flexibility in expected pattern of choices across individuals as, if we apply the principle of maximization to utilities rather than the expected monetary gain, people make decisions based on their own preferences and not the amount of money they stand to win. However, one of the basic axioms of the principle of expected utility maximization is that choices are consistent over time, which is not necessarily true.

Having outlined what constitutes a rational decision I will now go on to describe how and when reliable deviations from such a model occur.

1.2: Economically irrational decisions

The basic principle of the original exponential model of discounting utility was that discounting remained stable over time (Madden & Johnson, 2010). However, research repeatedly demonstrated reliable deviations from the discounting rate predicted by equation 1 (Lichtenstein

& Slovic, 1971; Madden, Petry, Badger & Bickel, 1997; Rachlin, Rainieri, & Cross, 1991; Jimura, et al., 2011) irrespective of whether the rewards were real or hypothetical (Madden, Begotka, Raiff & Kastern, 2003; Johnson & Bickel, 2002; Hinvest & Anderson, 2009; Lagorio, & Madden, 2005). The systematic departures from an exponential function led to Ainslie (1975) and, more famously, Mazur (1987) to model discounting rates using a hyperbolic function:

$$V = A/1+kD$$

Equation 2.

Where V is the value of the reward when it is available immediately, A is the amount of reinforcement, D is delay to delivery and *k* refers to the individuals' discount rate (Mazur, 1987). As shown by Figure 1.2, the hyperbolic function means that rewards that are temporally distant, are discounted at a steeper rate than those that are more immediate. This means that if an individual were asked at T_0 to decide between receiving the smaller-sooner reward at T_1 or the larger-later reward at T_2, though they might initially prefer the larger-later reward, the steeper discounting of delayed rewards leads to a *preference reversal*.

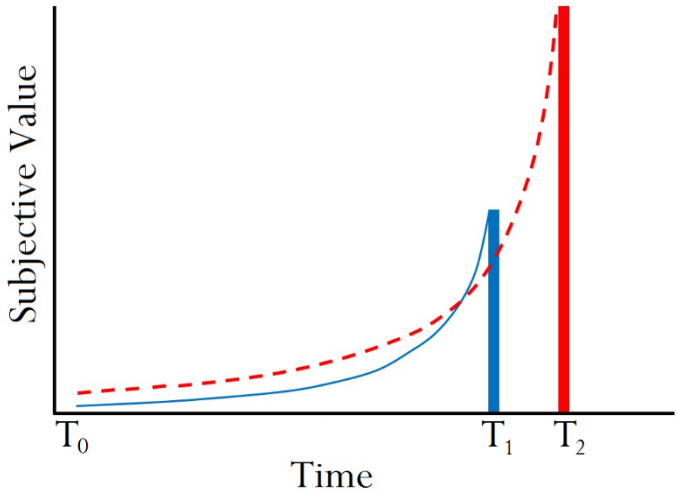


Figure 1.2 shows the preference reversal, where the bars represent the objective value of the rewards. The larger-later reward (red bar) is discounted more rapidly (red dashed line) than the smaller-sooner reward (blue line) as rewards are discounted hyperbolically over time.

In the ten years after Lichtenstein and Slovic (1971) first reported preference reversals, a number of economists argued preference reversals were an artefact of experimental methodology (Holt, 1986; Karni & Safra, 1987) and some sought to "discredit the psychologists' works as they applied to economics" (Grether & Plott, 1979, p. 623). However, preference reversals are not just a laboratory based phenomenon and instances of them in "the real world" spring readily to mind,

such as deciding to diet and then succumbing to the temptation of that piece of cake or choosing to quit drinking but then having that 'one swift pint' after work. As so aptly put by Schelling (1980), "people behave sometimes as if they have two selves, one who wants clean lungs and a long life and another who adores tobacco" (as cited by Ainslie, 2012, p.95).

A similar phenomenon to delay discounting, is probability discounting which refers to the reversal of preferences based on risk (Green & Myerson, 2004). According to utility theory, the *expected value* of a gamble should be calculated by averaging the possible outcomes and weighting them by their contingency: for example, the gamble: 20% chance of winning £75 or a 80% chance of winning £4.50, has an expected value of £18.60. However, such calculations are flawed in that they assume that an increase in probability will result in a ubiquitous increase in utility, irrespective of the initial probability; meaning that a 5% increase in contingency from 7 to 12% would be expected to have the same effect on utility as an increase from 95 to100%. This is known as the *independence axiom,* now considered to be a fundamental flaw of utility theory, and was first demonstrated to be reliably violated during decision-making in 1953 by Maurice Allais (as cited in Kahneman, 2011).

The principle, known as the *Allais paradox,* can be demonstrated using the following example of two decisions. For decision one, participants are asked to choose between gambles 'A', a 100% chance of winning €1,000,000, and 'B', a 10% chance of winning €5,000,000, an 89% chance of winning €1,000,000 and 1% chance of winning nothing. In such an instance, participants will pick 'A', but if we compare the *expected values* of each gamble we can see that the expected value of 'A' is €1 million whereas, 'B' is €1.39 million. Therefore, in decision one, it appears participants are maximising utility rather than value. Participants are then asked to make decision two between gambles 'C', with an 11% chance of winning €1,000,000 and an 89% chance of winning nothing, and 'D' which has a 10% chance of winning €5,000,000 and a 90% chance of winning nothing. When presented with this choice, participants are more likely to choose 'D', with an expected value of €500,000 over 'C' with an expected value of €110,000. Herein lies the paradox, in decision one participants maximise utility but for decision two they maximise expected value. Kahneman and Tversky (1979) attributed such inconsistencies in decision-making to the *certainty* and *possibility effect*. The former refers to when a gamble is extremely likely, individuals will often opt for a loss in order to attain certainty; a good example of this would be when plaintiffs settle out of court for a reduced amount of compensation, rather than take the risk of an unfavourable jury. Conversely, the *possibility effect* refers to when the chance of an outcome is very unlikely, the

contingency of its occurrence is over-weighted; such behaviour can be observed in individuals who buy lottery tickets or scratch cards in bulk or, more sensibly, the purchasing of insurance.

According to prospect theory, when making a decision one evaluates outcomes relative to a neutral reference point; for example, for financial outcomes, the neutral reference point could be thought of as what you feel entitled to or the price you might expect to pay for something. You compare the options to the reference point to interpret them as either a "loss" or a "gain". Importantly, the principle of diminishing sensitivity means that the perception of a loss or a gain is not subjectively constant, i.e. difference between €900 and €1,000 and €200 and €300 is the same, €100, but the subjective difference is not. This internal weighing and evaluation of options has the effect that people are, according to prospect theory, more sensitive to losses than gains; meaning that subjective value appears as an asymmetric S when modelled graphically (see Figure 1.3). Figure 1.3 shows that, when considering gains, a preference for certainty gives rise *risk-aversion*, in that people would rather a small, certain gain over a larger but doubtful gain. Conversely, when considering losses individuals are *risk-seeking* as they prefer a loss that is likely over a definite loss, even if the probabilistic loss exceeds the certain one (Kahneman & Tversky, 1979; Tversky & Kaneman, 1992; Kahneman, 2011).

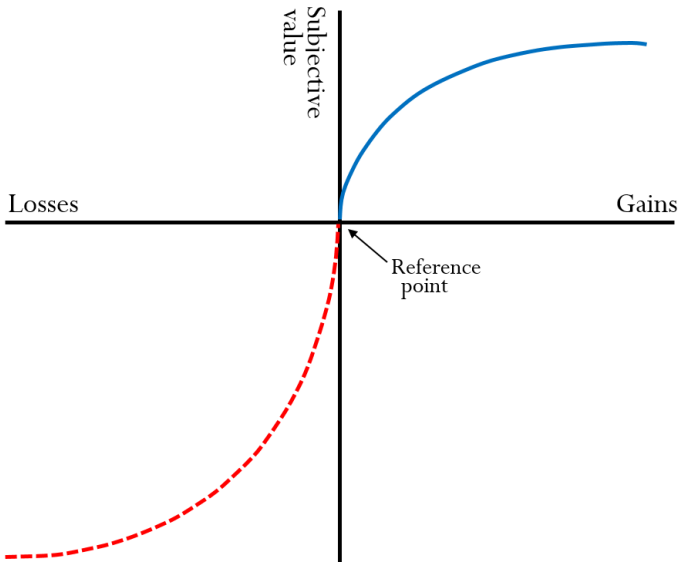


Figure 1.3: The line on this graph denotes the asymmetric S of subjective value for gains (blue line) vs losses (red dashed line) adapted from Kahneman and Tversky, (1979)

Experimental work concerning preference reversals and prospect theory were key factors leading to the development of the field of behavioural economics, which characterizes the allocation of behaviour within a closed system, with an emphasis on the conditions that influence consumption of commodities (Bickel & Marsch, 2001). As it seems reasonable that an agent should collect as much information pertaining to that choice as possible, before combining it so as to be able to make a decision (Christopoulos, Tobler, Bossaerts, Dolan, & Schultz, 2009). Therefore, a fundamental area in this approach is cost (be that effort, time, risk or a combination of these) and how cost can influence the experienced, predicted and decision utilities of a given reward. Two of the most studied means of examining utility are the effects of delay and probability, as, when choosing between rewards, agents attribute additional value to rewards that are available indubitably (certainty effect; Tversky &Kahneman, 1981) and without delay (immediacy effect; Keren & Roelofsma, 1995).

The study of the influences of delay and probability on reward utility are known as *delay-discounting* and *probability-discounting* respectively. In both forms of discounting paradigms, two rewards of differing magnitudes are presented. In a delay-discounting task the large-reward is available after a longer delay than the small-reward, whereas in probability discounting, the large-reward is available at a lowered probability compared to the small-reward. A cost is then applied to the large-reward by increasing the delay until (delay-discounting), or reducing the probability of (probability-discounting), reward receipt. These incremental changes to one reward, increasing the cost associated with it, eventually lead to a point when the predicted utility of both rewards is subjectively equal and, thus, a preference reversal (Green, Fry & Myerson, 1994).

1.3: Hedonistically irrational decisions

Preference reversals, known also as dynamic inconsistencies have been termed irrational (Monterosso, Piray & Luo, 2012; Rachlin & Raineri, 1992). However, Berridge and Alridge (2008) draw a distinction between what they term a genuinely irrational decision and *miswanting*. Miswanting is when one's predicted or remembered utility diverges from experienced utility (Kahneman, Fredrickson, Schreiber & Redelmeier, 1993). Examples of when this might occur would be if one underestimated the quality of an experienced utility (Simonson, 1990; Read & Loewenstein, 1995), misinterpreted one's current feelings (Kahneman & Thaler, 2006; Gilbert & Wilson, 2000) or over-estimated the emotional impact of an event (Ariely & Jones, 2010).

However, Berridge and Alridge (2008) argue that a decision based on a false premise, i.e. miswanting, is not irrational (Takahashi, 2007), but choosing against the option you think you will like best is. The question then remains, how does such a circumstance occur?

The first instance is when the affective state of the agent is manipulated, without their conscious awareness, through priming (Berridge & Winkielman, 2003). Research has shown that repeated exposure to stimuli increases how much they are liked on subsequent test (Zajonc 1968; Zajonc, Markus, & Wilson, 1974). Murphy and Zajonc, (1993) exposed participants to either neutral faces or faces expressing an emotion for very brief periods, so they were unaware of exposure. They then assessed their liking for Chinese ideograms and found that liking of the characters was significantly influenced by the expression of priming face, with smiling faces producing positive ratings, scowling faces producing negative ratings and neutral faces producing ratings not significantly different from a neutral shape; this finding was later replicated by Winkielman, Zajonc and Schwarz, (1997). Similarly, Winkielman, Berridge and Wilbarger, (2005) primed participants with angry or happy faces whilst pouring a fruit drink and found that exposure to the primes effected not only liking of the drink, but consumption behaviour and valuation as well; participants primed with smiling faces were poured and drank more fruit drink and were willing to pay more for a can than those exposed to angry faces. While such instances of subliminal priming are well replicated, Murphy and Zajonc, (1993) make the point that the effect of such primes is relatively diffuse and therefore appear to be a less than sufficient explanation for deviations from rational choice.

The second explanation for such irrational behaviour is when, despite the option being suboptimum in terms of 'liking' you select it because you 'want' it or, expressed another way, because your decision utility > predicted utility (Berridge &O'Doherty, 2014). Such an explanation means that irrational behaviour arises not from a failure to identify the option with the highest experienced utility but, rather, a dysregulation of motivation.

Contrary to reinforcement theories, motivational theories by Bindra (1974), Bolles (1975) and Toates (1986) proposed that unconditioned rewards were motivational incentives and that repeated pairings with conditioned cues produces a more complex relation than learning alone, by shifting motivation. The conditioned cues acquire the incentive motivational properties of the reward and thereby become incentives themselves.

This framework provided the basis for incentive sensitization theory (Berridge & Robinson, 1998; 2000), which argues that the underpinning of the motivational value of rewards and conditioned-cues is incentive salience, which is entirely distinct from any hedonic experience or contingency acquisition process. According to incentive sensitization theory, wanting and liking reflect two dissociable processes reliant on distinct neural underpinnings (Robinson & Berridge, 1998). *Liking* alone refers to the subjective, hedonic experience of pleasure (experienced utility) whereas *wanting* describes motivation (decision utility), which can be further divided into that which is under conscious control (wanting) and that which is not ('wanting'). Wanting is the expression of conscious desire, dependent on cognition, and therefore closely linked to predictions about the future and future utility (Berridge & O'Doherty, 2014). By contrast, 'wanting' refers to incentive salience, the means by which conditioned cues come to direct attention and motivate behaviour (Robinson & Berridge, 1998; Zhang, Berridge, Tindell, Smith & Aldridge, 2009). The ascription of incentive salience means the conditioned cue is now an incentive itself, which agents will exert effort to acquire (Robinson & Berridge, 1998) but attribution of incentive salience is modulated by two distinct modes of input. These modes are, firstly, the previously learnt associations between the reward and cue (Toates, 1986) and, secondly, the physiological or neurophysiological state of the organism at the time (Berridge, 2007; 2012; Berridge & Alridge, 2008). Once a cue is imbued with incentive salience it is said to be a 'motivational magnet' (Berridge, Robinson, & Aldridge, 2009) meaning that, whilst initially non-hedonic, it directionally focuses attention and motivation towards itself and its associated reward (Berridge, 2012). Interestingly, the response initiated by a CS motivational magnet is generally specific to the UCS with which it has been paired (Berridge, 2012) for example chewing or gnawing on cues that have been paired with a food reward (Davey, Cleland & Oakley, 1982) or attempting to drink cues that have been paired with liquid rewards (Hearst, 1974).

These types of stimulus directed behaviours are known as *sign-tracking* (Tomie, Brooks & Zito, 1989) and occur when incentive salience is attributed to the CS (also known as "autoshaping" (Brown & Jenkins, 1968) and "signal centred behaviour" (Jenkins, Barrera, Ireland & Woodside, 1978). When the CS is presented it initiates a period of extreme 'wanting' during which the motivation for the reward far exceeds its predicted hedonic value (Berridge, 2000), leading to the conditioned responses directed at the cue. In order to describe this, let's take the instance of an animal in an operant chamber within which it has previously been trained to receive sucrose paired with a cue. Prior to cue exposure the animal may want sucrose and be aware that it is in the correct context to receive it. Depending on how long the Pavlovian cue has been absent, it

may not express any reward seeking behaviour or might expend some effort at a similar to rate to previous reinforcement to acquire the reward. This is predicted utility. However, on presentation of the cue there is an increase in reward seeking behaviour, a sudden burst of effort, as a result of "wanting" sugar. When the cue is once again removed, its behaviour returns to its previous rate. This brief elevation of "wanting" is decision utility (Berridge & O'Doherty, 2014).

An essential caveat is that the responses are entirely superfluous to reward delivery, which will occur irrespective of the animals' actions (Robinson, Anselme, Fischer, & Berridge, 2014). Animals which engage in these CS directed conditioned responses, *sign-trackers*, find the CS alone an effective reinforcer and will work for access to it (Robinson & Flagel, 2009). An alternative form of conditioned response is to direct behaviour towards the location of reward delivery; this is called *goal-tracking* (Boakes, 1977; Robinson et al., 2014). Both sign- and goal-tracking are learned and at similar rates, as the CS remains a predictor to goal-trackers, just one without incentive salience (Meyer et al., 2012). The difference in conditioned response topography is thought to be because goal-trackers do not attribute the CS with the same incentive salience as sign-trackers, attributing it to the goal instead (Flagel, Akil &Robinson, 2009). A third behavioural phenotype, called *intermediates,* shows behaviour which oscillates between sign- and goal-tracking responses (Fitzpatrick et al., 2013).

Therefore, if we were to describe incentive salience in terms of utility, when 'wanting' exceeds liking, decision utility exceeds either predicted utility (Dickinson & Balleine, 2010; Berridge & O'Doherty, 2014). This is not to say, however, that irrational decisions cannot occur from the reverse (liking> wanting); but that, in terms of sign- and goal-tracking behaviour, wanting of the cue > liking of the reward meaning that, according to Berridge & Alridge (2008), sign- and goal-tracking represent irrational decisions as agents are choosing what they *want most* rather than what they *expect to like best*.

Having described how irrational decisions can occur economically and hedonistically, I will now go on to describe behaviours and traits associated with a propensity to make such decisions.

1.4: Correlates of 'irrationality'

Both preference reversals and sign-and goal-tracking behaviours have been described as irrational and, interestingly, shown to be associated with impulsivity, drug use and smoking behaviour.

Both sign- and goal-tracking (Meyer et al., 2012) and rapid discounting of probabilistic or delayed rewards (Ainslie, 2012; Kirby & Herrnstein, 1995; Green & Myerson, 2010) have been termed impulsive behaviours. In human research, this assertion is supported by the studies illustrating a strong correlation between discounting rates and personality measures of impulsivity (Alessi & Petry 2003; Madden et al., 1997; Reynolds et al. 2006).

However, it appears that in addition to trait impulsivity, state impulsivity can also influence decision making. Guerrieri, Nederkoorn, Schrooten, Martijn & Jansen (2009) induced impulsive decision making by asking participants to read a short story before the task, under the guise of it being a memory test. Those primed into an impulsive state consumed significantly more calories than participants who heard a control story. The researchers suggested this was due to heightened reward sensitivity, a hypothesis supported by the work of Martin and Potts (2009) who compared participants with low and high scores on the Barratt Impulsivity Scale-11 (BIS-11) and found that those with the higher scores were more sensitive to the value of the rewards being offered, and this preoccupation superseded valuation of potential repercussions leading to maladaptive, impulsive decisions. Similarly, de Wit, Flory, Acheson, McCloskey and Manuck (2007) found a positive correlation between the *non-planning* subscale of the BIS-11, which assesses how future oriented an individual is and their delay-discounting rate. Those who are future oriented are thought to be better at predicting what they might want at a later date, which leads to less rapid discounting of delayed rewards. A possible explanation for this is that when individuals make decisions they do so based on the evaluation of the option they are selecting, but also considering the alternatives (Bertoux et al., 2014). This process allows for appraisal of what has and could have been and, when expectancy fails to live up to actuality, leads to regret (Canessa et al., 2009).

In animal models, rats bred to display high levels of locomotor activity are significantly more likely to show sign-tracking, as opposed to goal-tracking, responses (Flagel et al., 2009). Tomie, Aguado, Pohorecky and Benjamin, (1998) suggested that the reason for this is that when selectively breeding for locomotor activity other traits, such as impulsivity, were also selected for. A more recent investigation by Lovic, Saunders, Yager and Robinson (2011) found that, compared to goal-trackers, sign-trackers showed higher levels of impulsive action but not impulsive choice. Sign-trackers showed more premature responses on a two choice serial reaction time task (2-CSRTT), were less efficient in a differential reinforcement of low rates task (DRL), but showed less rapid discounting in a delay-discounting task. Perry, Larson, German, Madden

and Carroll (2005) grouped rats as either high or low impulsivity based on temporal discounting rates. Following this, the rats were trained to self-administer cocaine. Significantly more rats in the high-impulsivity group acquired the behaviour than the low-impulsivity group. Similarly, Kearns, Gomez-Serrano, Weiss and Riley (2006) showed that Lewis rats, known for being more impulsive (Anderson & Woolverton, 2005) and of acquiring drug behaviour more rapidly (Martin et al., 1999; Pescatore, Glowa & Riley, 2006) than Fischer rats, also acquired sign- and goal-tracking responses significantly faster than Fischer rats. This indicates that a propensity to rapidly discount future rewards is related to drug use and, potentially, sign- and goal-tracking behaviour.

Bickel, MacKillop, Madden, Odum and Yi (2015) attribute the recent increased interest in delay- and probability-discounting procedures to steep discounting of delayed rewards (i.e., more impulsive) being repeatedly demonstrated to correlate with degree of substance abuse (MacKillop, Amlung, Few, Ray, Sweet and Munafò, 2011;Yi, Mitchell & Bickel, 2010; Andrade & Petry, 2012; Crean et al., 2000). Moreover, more rapid discounting for future rewards, compared to controls, has been observed in addicts across a number substances including opioids (Kirby, Petry & Bickel, 1999;Madden et al., 1997), cocaine (Coffey Gudleski, Saladin & Brady, 2003), MDMA (Morgan, Impallomeni, Pirona & Rogers, 2006; Morgan, McFie, Fleetwood & Robinson, 2002), alcohol (Petry, 2001a;Richards, Sabol & deWit 1999) and cigarettes (Baker, Johnson & Bickel 2003; Bickel, Odum & Madden, 1999;Mitchell, 1999; Reynolds, 2004; Ohmura, Takahashi & Kitamura, 2005).

Verdejo-García, López-Torrecillas, Giménez and Pérez-García, (2004) suggested that, as many drugs (e.g. cannabis, MDMA, cocaine, amphetamines and heroin) produce neurological changes that decrease regions of the cortex associated with the executive system, it might be expected that substance abusing individuals opt for the smaller-sooner reward over the larger-later reward. Further to this, damage to the executive system might help explain how and why someone would, repeatedly, make a choice knowing that this choice will later entail receipt of a negative consequence or outcome; why drug addicts will risk a huge amount in the long term for a small short term gain (Bickel et al., 2007). In support of this, manipulations that tax the executive system have been shown to increase discounting rate (Bickel & Yi, 2007).

Bickel, Jarmolowicz, Mueller and Gatchalian (2011) argued that addicts' attribute extreme value to their abused reward and demonstrate a marked preoccupation with acquiring it as rapidly as possible, a tendency they referred to as *reinforcer pathology*. Research indicates that in some

instances this effect is, to an extent, reversible; ex-addicts discount the future less than current addicts and in some cases the same as controls (Bickel et al., 1999). Put in terms of utility, the peak in decision utility exceeds prediction or remembered utility leading to consumption, which provides an explanation for relapsing behaviour in drug addicts (Berridge & O'Doherty, 2014). Alternatively this can be explained by their chosen reward being imbued with incentive salience, making it 'wanted' and therefore, increasing the subjective experience of cost when receipt is delayed.

Research into the relationship between sign and goal-tracking behaviour and substance abuse has shown that a propensity towards sign or goal-tracking conditioned responses is an indicator of susceptibility to drug abuse (Tunstall & Kearns, 2015; Robinson, Yager, Cogan, & Saunders, 2014). Furthermore, animals exposed to drugs and drug cues in adolescence showed more sign-tracking behaviours than those animals tested in adulthood (Anderson & Spear, 2011). Sign-tracking behaviours have been likened to relapsing in drug abuse, in that previously reward paired cues can produce psychomotor activation or reward seeking, even after abstinence (Tomie, Grimes, & Pohorecky, 2008; Saunders & Robinson, 2010, 2011; Yager & Robinson, 2013). Sign- and goal-tracking conditioned responses have been shown to be exacerbated by the effects of a number of drugs of abuse including opioids (DiFeliceantonio & Berridge, 2011), amphetamine (Doremus-Fitzwater & Spear, 2011; Holden & Peoples, 2010), cocaine (Flagel, Watson, Akil & Robinson, 2008) and nicotine (Palmatier et al., 2013). Although the facilitating effects if the drugs are not ubiquitous across response groups, with sign-trackers being more sensitive to the psychomotor activating properties of amphetamine and cocaine than goal-trackers (Doremus-Fitzwater & Spear, 2011; Flagel, et al., 2008).

Sign- and goal-tracking responses have also shown to be dissociable in other ways; reward probability has a differential effect on response rates of each. A known factor in the attribution of incentive salience is the probability of reward receipt after cue onset. Brown and Jenkins (1968) suggested that conditioned responses are resultant of a positive correlation between cue presentation and a biologically salient event; the reasoning being, the more reliable a cue, the more easily recognizable one can expect it to be (Griffiths & Mitchell, 2008), increasing its associability (Le Pelley & McLaren, 2003). However, this assertion does not accurately describe sign-tracking which has been demonstrated, using animal models, to be potentiated by uncertainty (Boakes, 1977; Anselme, Robinson & Berridge, 2013; Robinson, Anselme, Suchomel & Berridge; 2015; Davey et al., 1981; Davey & Cleland, 1982) whereas goal-tracking responses

are not. Similarly, research in humans using pathological gamblers has shown that "near misses" induced more activation in reward-related neurocircuitry than "big-wins" (Chase & Clark, 2010). Accounts of why uncertain rewards induce more activation than certain rewards have generally involved emotion; Loewenstein (1987) suggested that delayed rewards increased a sense of anticipation thereby increasing the overall utility of the reward by prolonging the experienced utility of consumption (Loewenstein, 1987); which he termed "savouring" (p.667). There are instances of negative discounting, positive events might be purposefully delayed in order to "extend the otherwise fleeting benefit provided by consumption" (Loewenstein, 1987; p. 672), such as delaying a holiday. Conversely, Papini (2006) argued that uncertain rewards induce a sense of frustration which potentiates responding; however, this account has been deemed insufficient with the observation that at maximal uncertainty (50%) frustration cannot occur as the possibility of receiving and not receiving the desired outcome is equal. Most recently, Anselme (2015) forwarded the incentive hope model, which advances that uncertainty increases responding by increasing interest in the task (Anselme & Robinson, 2013). This is proposed to occur through two processes wherein the process of receiving a reward when there is a possibility one will not increases the utility of that reward on receipt. Secondly, that uncertain rewards invigorate responding by diminishing conditioned inhibition.

1.5: Empirical measures of 'irrationality'

In order to assess the impact of probability, impulsivity and drug addiction on sign- and goal-tracking and discounting of probabilistic and delayed rewards and sign- and goal-tracking behaviours, empirical research has been carried out using animal and human models. In the next section I will assess the modes used in non-human animal and human models, with particular focus on the translational aspects of each, for investigating of economic (discounting) and hedonistic (sign- and goal-tracking) irrationality.

1.5.1: Non-human animal models of discounting.

One of the earliest methodologies for assessing discounting rates in animals was the adjusting-delay procedure (Mazur, 1987). Agents are presented with a small reward available at a fixed delay or a large reward the delay before delivery of which changes based on previous selections. Animals experienced two forced and two choice trials each block, if the small reward is selected on both choice trials the delay until large reward is decreased by one second in the subsequent

block. Whereas, if the large reward is chosen during both choice trials, the delay before reward delivery is increased by one second in the following block. A similar method to this is the adjusting-amount procedure (Richards, Mitchell, DeWit & Seiden, 1997) wherein subjects are presented two options: a large, delayed and a smaller, adjusting reward. The large reward is kept constant but the smaller reward changes incrementally based on the previous choices; the magnitude of the small reward is increased if the large-reward, and decreased if the small-reward, is selected. In addition to this, if an option is selected more than twice consecutively a forced trial of the other reward follows. The most commonly utilised model of discounting in animals is the Evenden and Ryan (1996) procedure wherein the individual selects between a small and a large reward the magnitude of which remains constant throughout the testing session. However, the procedure is split into blocks and where delay before the small reward remains constant, the delay before the large reward changes between blocks, typically starting at zero seconds and finishing with a minute delay in the final block. Furthermore, this methodology has been adapted for the examination of probability discounting in rats (Simon, Gilbert, Mayse, Bizon & Setlow, 2009; Nasrallah, Yang, & Bernstein, 2009) although has not been extended to mouse models.

These animal models have several common features. Firstly, the animal must initiate the trial by an action, for example a nose poke or key peck. Secondly, options are presented in the form of forced trials wherein the trial does not end until the animal has selected the option presented and experienced the consequences of that selection. Finally, there is a post reward inter-trial interval (ITI). The ITI is necessary as it controls for animals repeatedly selecting the small reward so as to minimize delay and maximize overall reinforcement; by making the ITI a fixed length, the local and maximum rate of reinforcement for the small reward is kept lower than the large reward ensuring that selection of the smaller reward demonstrates impulsive decision making, rather than a means of maximizing reward receipt (Blanchard, Pearson & Hayden, 2013).

1.5.2: Human models of discounting

The most commonly used means of assessing discounting behaviour in humans is self-report questionnaires such as the Kirby and Marakovi**ć**'s delay discounting 21-item (1996), Kirby, Petry & Bickel's delay discounting 27-item (1999) and Madden, Petry & Johnson's (2009) 30 item probability discounting questionnaires. These measures are all examples of what are termed 'monetary price lists', wherein participants need to choose between two items and their relative costs e.g. "*Would you prefer £35 today or £49 in 23 days?*" Or, in probability discounting, "*Would you*

prefer £20 for sure or a 1-in-10 chance (10%) of winning £80". Research has shown that monetary price lists are reliable across multiple test sessions (Lagorio & Madden, 2005) and, in addition to this, they are quick to administer, interpret and allow for examination of long delays. However, there have been a number of objections to such measures. The first is that items, such as the example above, do not explicitly state the options' 'missing zeros' and that their inclusion makes the question much more explicit (Magen, Dweck, & Gross, 2008). For example, "*Would you prefer £35 today and £0 in 23 days or £0 today and £49 in 23 days?*". Magen, Dweck, & Gross, (2008) found significantly lower levels of impulsiveness when using questions such as these compared to the traditional "hidden-zero" items. A potential criticism of such an adaptation is that it does not seem clear how such an amendment can make sense for probabilistic larger rewards and there is also a possibility that the inclusion of the "missing zeros" may be having an impact by influencing either loss aversion or the magnitude bias rather than by assessing discounting more accurately. Another criticism of monetary price lists is that, unlike animal models, the participants do not experience the delay associated with their reward choice, which means that participants may exaggerate the extent of their patience or risk aversion. As described so succinctly by Odum (2011), deciding between tangible rewards and experienced delays is quite distinct from choosing between those one has imagined.

Unlike other forms of assessment, the computerised Experiential Discounting Task (EDT) (Reynolds & Schiffbauer, 2004) allows participants to experience trial-by-trial consequences of their decisions (Reynolds, Richards, & de Wit, 2006). In a method similar to assessment of delay discounting in animals, a computer program is split over multiple delay blocks and participants choose between a standard reward of (US$ 0.30) and an adjusting smaller reward. If the large reward is selected, participants must wait for the designated delay period before "banking" their winnings. As it includes real delays, it is thought that the EDT is more sensitive to factors such as delay aversion than hypothetical question-based discounting tasks (Reynolds et al., 2006). In support of this, experiential tasks have been shown to produce more impulsive choices than questionnaire assessments of discounting (Reynolds, 2006), however this may be due to the significantly smaller reward sizes and reduced delays utilized in such tasks.

Similarly to animal experiments, the EDT also includes forced trials, to ensure participants experience all options; however, unlike animal experiments, these forced trials are contingent on previous responding. In animal discounting models, there is also usually a post-reward ITI, to equalise trial length, which is also not included in the EDT. Reynolds (2006) justified this by

arguing that outside the laboratory choosing a large reward often involves subjective costs. However, exclusion of the post-reward ITI means that the selection of the supposedly "maladaptive and impulsive" small option would allow for greater local and overall rate-maximization (Logue, Peña-Correal, Rodriguez, & Kabela, 1986; Bickel, MacKillop, Madden, Odum & Yi, 2015).

Unlike traditional delay discounting assessments, the receipt of the large reward in EDT is both delayed and probabilistic (the chance of receiving cash 35% across all blocks). This additional probabilistic component to the EDT might explain why it has not been found to correlate with alternative delay discounting measures (Peters, Petry, LaPaglia, Reynolds, & Carroll, 2013). Further to this, Smits, Stein, Johnson, Odum and Madden (2013) discovered that participants were utilising the probabilistic component of the EDT to drive up their reward by selecting the large reward in order to increase the value of the small reward. The authors liken this to the concept of *internality*, described by Herrnstein, Loewenstein, Prelac and Vaughn (1993), that the results of current decisions are the consequence of past choices. Interestingly, in Smits et al.*'s* study, substance abusers failed to utilize this factor and therefore did not maximize their rewards as efficiently as drug naïve matched controls. However, it raises a crucial point about the EDT which is that the probabilistic element actually allows for greater local and overall reward and therefore does not represent an accurate model of delay discounting.

Compared to delay discounting, behavioural tasks examining probability discounting are relatively limited. A potential explanation for this is that measures of probability discounting are usually classified under the umbrella terms of "risky decision making" and "gambling tasks" which aim to examine moderators of such behaviour, rather than the mediating effect of reward contingency itself (for example the Rogers Decision Making task (Rogers et al., 1999; Murphy et al., 2001; George, Rogers & Duka, 2005)). The difficulty with such tasks is that as the trials revolve around participants betting it is not possible to calculate a discounting function from the results. A well-established and replicated model of probability discounting was developed by Richards, Zhang, Mitchell & DeWit (1999) and is based on the adjusting-amount procedure, previously described. Participants were asked to complete a number of choices between a small and large monetary rewards on a computer and reward sizes titrated based on previous answers until an indifference point was reached. While this model is superior to pen-and-paper measures of discounting, in that it is fully randomised and determined by each individual's choice, the participants were reimbursed via a lottery so were given a single reward for all their choices. In addition, the

protocol still relies on participants reading the question and making a decision based on the consequences they have imagined, rather than experiencing the loss based on their choice, as in delay-discounting paradigms.

1.5.3: Animal models of sign- and goal-tracking

Assessment of sign and goal-tracking behaviour has been carried out predominantly in animals using Pavlovian conditioning. Such paradigms will, typically, present a stimulus (CS) within a close temporal proximity to a reward (US); through repeated exposure, the CS comes to modify and shape the subject's behaviour. Animal models have used a wide variety of localizable CSs, including levers (Davey, Oakley & Cleland, 1981), static lamps (Holland, 1980), touchscreens (Horner et al., 2013) and restrained conspecifics (Timberlake, 1983; Timberlake & Grant, 1975).

Until recently a problem with research examining sign- and goal-tracking was the criteria by which animals were designated sign- or goal-trackers varied across studies. One such means was called the "rank-order-split" which involved splitting the sample into thirds based on absolute number of conditioned responses (e.g. lever presses) and designating the highest responders as sign-trackers and the lowest as goal-trackers (Bedard, Maheux, Levesque, & Samaha, 2011; Robinson, et al., 2014; Robinson & Flagel, 2009; Saunders & Robinson, 2010). Alternatively, Flagel et al. (2007) convert responses during a selection of sessions into z scores and classify the animals as sign-trackers if they show a positive z-score of .5 or and as goal-trackers if they have a negative z-score of −0.5 or lower.

This variation in sign and goal-tracker identification hampered cross study comparisons until a standardized means of classifying individuals was established by Meyer et al., *(*2012). The *Pavlovian conditioned approach* index (PCA index) is calculated on the basis of the three properties of a Pavlovian stimulus; their ability to bias attention, become objects of desire (to become 'wanted') and to generate the conditioned motivational state that induces reward seeking (Bindra, 1974; Toates, 1986; Berridge & Robinson, 2003; Meyer et al., 2012). The PCA index compares the ratio of head entries to lever presses (response bias), the difference in probability in making a goal or signal directed response (probability difference) and the latency until a subject makes a goal or signal directed response (latency score). These 3 values are averaged to produce a PCA score; this is done over multiple sessions (usually the last three) and then the PCA scores are averaged to produce the PCA index.

1.5.4: Human models of sign- and goal-tracking

While sign- and goal-tracking has been demonstrated in a variety of animal species including birds (Burns & Domjan, 2000, Brown & Jenkins 1968), fish (Nilsson et al., 2008) and rodents (Olshavsky et al., 2015; Horner et al., 2013), research into sign- and goal-tracking in humans is limited. Deckner, Wilcox, Miasto & Blanton (1980) and Siegel (1977) compared signal directed behaviour in slowly and normally developing children and found some evidence for an internally generated conditioned response which was intrinsically rewarding, as previously shown in animal studies. However, in both instances the participant numbers were very low. Subsequently, both Pithers (1985) and Wilcove and Miller (1974) demonstrated limited sign-tracking in humans using a coin dispenser. Participants had access to a lever and, independently of any participant action, change (2¢ and 1¢ respectively) would be delivered into a tray. However, Pithers' protocol does not allow for the examination of goal-tracking behaviour as participants were instructed to not collect money until the end of the session. In the follow on assessment for Wilcove and Miller's study, participants were asked about the degree of control they exerted over coin delivery and the results suggested that participants were using their lever responses as a means of hypothesis testing, which led the authors to conclude that the response differed from that shown in non-human animals. Newman, Wolff and Hearst (1980) demonstrated sign-tracking in a series of experiments examining feature positive effects, and found college students were increasingly likely to touch the positive cues in the experiment as time went on, even though the response would not influence reinforcement. The authors suggested that one possible explanation for this behaviour was as a means of making the stimuli more distinctive, so as to aid discrimination.

Sign- and goal-tracking have since been studied using an eye tracker; Garofalo and di Pellegrino (2015) were able to identify response groups based on dwell time making it equivalent to animal models which used orienting as a conditioned response (Olshavsky et al., 2015). A benefit of the eye tracking methodology is that it allows for the examination of attentional models and how reward probability influences the impact a cue has on behaviour. Animal models have demonstrated that probability has a pronounced effect on the advent of sign- or goal-tracking response topography and the use of an eye-tracker allows for this effect to be examined in humans as well. Garofalo and di Pellegrino (2015), however, did not make full use of the measures available to them to examine cue directed behaviour as their assessment was based predominantly on dwell time, whereas eye-tracking measures allow for a wide range of measurements, some of which would be, to a degree, equivalents of measures used in animal studies.

1.6: The importance of homology in translation:

It is important, and appropriate, to state from the outset that while learning mechanisms are undoubtedly important for maladaptive drug seeking behaviours to arise, that genetic and environmental factors, throughout development, are also integral to vulnerability; however, the focus of this thesis is around learning mechanism surrounding reward theory so I will limit the following section to such.

There is substantial evidence supporting the assertion that drug and natural rewards (such as food or sex) are underpinned by the same neural substrates (Pelchat, 2002; Kelley & Berridge, 2002). For example, the affective expressions naturally induced by sweet tasting stimuli are similar across a number of species including rats and humans (Berridge, 2000). When experiencing a sweet taste, animals show distinctive expressions indicative of 'liking' such as licking their lips; conversely, bitter tastes elicit mouth gapes and flailing forelimbs (Berridge, 2007). From an evolutionary standpoint, pleasure must be essential to the fulfilment of basic drives (Kelley & Berridge, 2002; Berridge & Kringelbach, 2008). Addiction, therefore, has been described as the process through which neural systems underpinning natural rewards are usurped (Hyman, Malenka & Nestler, 2006). As these networks are comparable in rodents and humans (Balleine & O'Doherty, 2010), animal models have been used as a means of, what Ahmed (2012) termed, "reverse psychiatry" (p.108); wherein researchers attempt to render animals addicted to substance known to induce the same state in humans. The aim of this process being to glean some insight into the aetiology of or potential treatments for drug addiction from non-human animals (Ahmed, 2012).

There is substantial evidence suggesting that, contrary to early theories, addiction does not arise solely due to homeostatic dysregulation and subsequent withdrawal but that associative memories, particularly those of drug paired cues, come to exert considerable influence on behaviour (Tiffany, 1990; O'Brien, Childress, Ehrman & Robbins, 1998). In the pursuit of natural goals, the procurement of a reward (i.e. satisfaction of a drive) is positively reinforcing and apt to be repeated, leading to the acquisition of complex sequences of behaviours (Hyman et al., 2006). However, following prolonged reiterations or drug use, these natural pathways can be hijacked (Haber & Behrens, 2014).

Dysregulation of Pavlovian or instrumental learning are known to contribute to the advent of neuropsychiatric disorders such as drug-addiction, depression and schizophrenia (Keeler & Robbins, 2011; Murray et al., 2008; Corlett et al., 2007; Gradin et al., 2011); of these, drug addiction has been modelled most effectively using animals as the drugs themselves are thought to contribute, at least in part, to the advent of this disorder (Hyman, et al., 2006). However, addictive behaviour is thought to arise due to a number of factors including dysfunction of neurotransmitter systems (Nestler, 2005; Kelley & Berridge, 2002), prefrontal executive control (Belin, Jonkman, Dickinson, Robbins & Everitt, 2009) and transcription, such as CREB (Nestler, 2004). From a pathophysiology level, non-human animal experiments allow for investigation of chronic exposure to drugs, using a wide range of doses (Ator &Griffiths, 2003) and insight into how Pavlovian and instrumental learning, across contingencies, influences the functional connectivity of the brain (Haber & Behrens, 2014). A considerable problem with investigating the factors contributing to human addiction is that investigations are retrospective, making it extremely difficult to determine causality whether behavioural discrepancies are the cause or consequence of a propensity to abuse drugs (Olmstead, 2006). Conversely, animal models allow for the examination of substance naïve individuals, with a known genetic background, pre- and post-drug exposure (Peña-Oliver et al., 2015). Therefore, translational psychopharmacological, imaging and behavioural experiments are integral for understanding the mechanisms and development of neuropsychiatric disorders (Haber & Behrens, 2014). For this reason, it is imperative to aim for standardization between and within experimental laboratories and, as much as possible, species. As described by Talpos and Stickler (2013) all research, but translational research in particular, must be accurate, sensitive, specific, robust and reliable. The application of findings from non-human subjects to human samples must always be tentative (Ahmed, 2012; Stephens et al., 2010), however, to reduce the possibility of being misled methodologies must be as homologous as possible.

1.7: Aims of this thesis:

This thesis aims to examine economically and hedonistically "irrational" behaviour within human and non-human animal samples. Having explored the existing measures of such, a central aim of this series of experiments is to design reliable translational behavioural measures of such behaviour; specifically, probability and delay discounting and sign and goal-tracking.

Within animal samples, propensity to sign- or goal-track is reflective of susceptibility to drug abuse (Tunstall & Kearns, 2015; Robinson et al., 2014) therefore it would be extremely useful to develop a means of assessing such a predisposition in humans. Having established the method for assessing sign and goal-tracking within a human sample, I aim to identify the response topographies of intermediates, sign- and goal-trackers already observed in non-human experiments. Furthermore, as reward paired cues have been shown to elicit reward seeking and psychomotor activation in animal samples even after extinction (Tomie et al., 2008; Saunders & Robinson, 2010; 2011; Yager & Robinson, 2013), this thesis aims to examine how devaluation, through reward-contingency and delay before reward receipt, and presentation of multiple cues influences the utility of reward in both discounting and autoshaping. Existing research (Oberlin, & Grahame, 2009; O'Tousa et al., 2015) has shown that delay discounting can be reliably replicated using a mouse paradigm; in this thesis, I aim to develop a model of probability discounting in mice. As discussed, individual differences such as drinking behaviour, drug experience or trait impulsivity level can contribute to the expression of irrational decision making (de Wit et al., 2007; Baker et al., 2003; Bickel et al., 2011); in this thesis I aim to examine how such factors interact with devaluation by pre-exposure, reward-contingency and delay before reward receipt to influence economically and hedonistically "irrational" decisions.

This thesis also aims to explore the relationship between trait impulsivity, as measured by the BIS-11, delay discounting rate, as measured by the Kirby, Petry and Bickel (1999), and probability discounting rate, Madden, Petry and Johnson's (2009). In addition to this, whether the effects of prime previously reported elsewhere (Guerrieri et al., 2009) can also influence discounting rates and whether such primes influence individuals with divergent levels of trait impulsivity differently.

2. General Methods:

The experiments conducted with human participants shared a number of methodological similarities and measures; in order to avoid repetition of these details later, a description of various measures and the mode of analysis is defined here. Details of the distribution of classifications can be found in the method section of each experiment.

2.1: General procedure:

All behavioural task data collection took place in individual computer cubicles the human psychopharmacology laboratory on the University of Sussex campus. Participants were recruited using posters, word of mouth, SONA or social media. All participants were required to read an information sheet, give full written consent and were debriefed as to the aims and rationale of the experiments on completion and reimbursed with either £6 per hour or equivalent course credit for their time. All experiments were ethically approved by University of Sussex Cluster-based Research Ethics Committee (C-REC) and participants were informed of this before taking part. Partial eta squared (partial η^2) effect sizes have been included after each significant effect to aid interpretation. The benchmarks for partial η^2 are as follows: a value of 0.02 or larger indicates a small, between 0.13 and 0.26 denotes a medium, and in excess of 0.26 is a large effect (Cohen, 1988).

2.2: Eligibility requirements

In order to take part in the behavioural tasks, participants had to be aged18-45, have never received treatment for alcohol, drug or gambling addiction and not be taking any prescription medication, apart from the oral contraceptive pill.

2.3: Questionnaires:

2.3.1: Barratt Impulsiveness Scale, Version 11 (BIS-11; Dimoska, Johnstone, Barry, & Clarke, 2003):

This 30 item questionnaire was presented in a table, with the 4 point scale, ranging from "rarely/never" to "almost always", shown in columns (see appendix 1: 1.1). Participants were asked to indicate how true each statement was for them using pen and paper. This measure consists of three primary, and six secondary, subscales. The first, attention, assesses how well an individual can wilfully maintain their attention using statements such as "I concentrate easily" and "I squirm in lectures or plays". The second primary subscale, motor, examines whether an

individual acts without thinking with items such as "I buy things 'on impulse'" and "I change jobs". Finally, the non-planning subscale measures how future oriented a person is, with items such as "I plan tasks carefully" and "I am more interested in the present than the future". The Barratt Impulsivity scale is a well-established measure of impulsivity and, as such, benchmarks of "impulsivity classification" have been established. According to a review of studies using BIS-11 by Stanford et al. (2009), scores between 52-71 represent a "normal" level of impulsivity, scores lower than 52 indicate that the individual is either "overly controlled" (Knyazev & Slobodskaya, 2006) or not being entirely honest in their responding (Helfritz, Stanford & Conklin, 2006) and, finally, a score of 72+ indicates a "highly-impulsive" individual (Houston & Stanford, 2005). For this reason, analysis was carried out using these classifications throughout.

2.3.2: Kirby, Petry and Bickel (1999) delay-discounting questionnaire:

27 item questionnaire was presented in a table. Participants were asked to read the item, e.g. "*would you prefer £12 today or £75 in 8 months?"* and then check a box to indicate whether they chose the small-sooner reward or the large-later reward for each item (see appendix 1: 1.2 for reproduction). The items were presented in the same order as in the original methodology as this was controlled for sequencing effects. Discounting rates, k values, were then derived from the pattern of their choices. This was done by separating the 27 items into the 3 subscales (small, medium and large) and then sorting them in order of k at indifference. "K at indifference" is a participant's discount rate if the smaller-sooner reward and larger later reward were of equal subjective value to the participant. In order to ascertain an individuals' discounting rate, we must calculate the midpoint between last selection of one reward (small-soon or large-later) and first selection of the other (small-soon or large-later).

For example, question 13 (the first row on table 2.1) asks if one would prefer "£34 today" or "£35 in 186 days". An individual with a discounting rate of 0.00016 would be indifferent between those two rewards. This means that if an individual chooses the large reward we can infer that their discounting function is less than 0.00016. If then for question 20 (row four on table 1), when asked to choose between "£28 today" or "£30 in 179 days", the same person were to select the smaller sooner option we can infer their discounting rate is between 0.00016 and 0.0004 (k at indifference for question 20, see table 2.1). By using these trials together, we can take the midpoint and use this as an estimate of delay discounting rate. In the current experiments, the geometric mean was used in order not to under-weigh the lower k boundary. For the current example the k value would be 0.00025. This was done for each of the subscales in turn and then the 3 values were averaged to calculate the overall discounting rate.

As there are 9 questions per subscale this means there are 8 discounting rates for each and 2 discounting rates which represent an individual who chose all immediate rewards or all delayed rewards. If a participant was inconsistent in responding, k values were estimated by calculating the midpoint between their first and last consistent choice. If a participant did not become consistent at any stage of responding, i.e. their responding appeared random, they were excluded from further analysis.

Order presented	Smaller-sooner reward	Larger later reward	Delay (days)	K at Indiff.	k rank	Magnitude subscale
13	£34	£35	186	0.00016	1	small
1	£54	£55	117	0.00016	1	medium
9	£78	£80	162	0.00016	1	large
20	£28	£30	179	0.0004	2	small
6	£47	£50	160	0.0004	2	medium
17	£80	£85	157	0.0004	2	large
26	£22	£25	136	0.001	3	small
24	£54	£60	111	0.001	3	medium
12	£67	£75	119	0.001	3	large
22	£25	£30	80	0.0025	4	small
16	£49	£60	89	0.0025	4	medium
15	£69	£85	91	0.0025	4	large
3	£19	£25	53	0.006	5	small
10	£40	£55	62	0.006	5	medium
2	£55	£75	61	0.006	5	large
18	£24	£35	29	0.016	6	small
21	£34	£50	30	0.016	6	medium
25	£54	£80	30	0.016	6	large
5	£14	£25	19	0.041	7	small
14	£27	£50	21	0.041	7	medium
23	£41	£75	20	0.041	7	large
7	£15	£35	13	0.1	8	small
8	£25	£60	14	0.1	8	medium
19	£33	£80	14	0.1	8	large
11	£11	£30	7	0.25	9	small
27	£20	£55	7	0.25	9	medium
4	£31	£85	7	0.25	9	large

Table 2.1: shows items from Kirby, Petry & Bickel (1999) questionnaire ranked by k value. "Order presented" shows numerical order items appeared in questionnaire; "delay (days)" shows the delay before larger-later reward in days; "k at indifference" shows the value of discount rate at which smaller sooner reward and larger later reward are equal subjective value according to hyperbolic function (equation 2 in general introduction), "k rank" shows items with the same k grouped in ascending reward size order. "Magnitude subscale" shows which subscale items belonged to according to reward size.

2.3.3: Madden, Petry & Johnson's (2009) probability discounting questionnaire:

Madden, Petry & Johnson's (2009) 30 item probability-discounting questionnaire was included in a table (see appendix 1: 1.3). The questionnaire includes items such as "*would you prefer £20 for sure or a 1-in-10 chance (10%) of winning £80*" and participants were asked to check a box to indicate whether they would prefer the small certain reward or large uncertain reward. Again, the items were presented in the same order as in the original methodology. Similarly to the delay-discounting questionnaire, the probability discounting questionnaire was analysed by separating the 30 items into the 3 subscales (small, medium and large)

Discounting rates, h values, were then derived from the pattern of their choices. This was done by separating the 27 items into the 3 subscales (small, medium and large) and then sorting them in order of h at indifference. "h at indifference" is a participant's discount rate if the smaller certain reward is subjectively equal in value to the larger probabilistic reward. An individual's h value was derived in the same way described for the delay discounting questionnaire.

For example, question 1 (the first row on table 2.2) asks if one would prefer "£20 for certain" or "a 10% (1 in 10) chance of winning £80". An individual with a discounting rate of 0.33 would be indifferent between those two rewards, if we imagine a participant selected the large probabilistic reward for this question. For question 2 (row four on table 2.2), asks would you prefer "£20 for certain" or "a 13% (1 in 8) chance of winning £80", meaning the h at indifference is 0.45 for question 2. If the same person were to small certain option we can infer their discounting rate is between 0.33 and 0.45, giving this participant a discounting rate of 0.39. If a participant always selected the certain or probabilistic reward, their h value was estimated using the highest and lowest values shown on table 2.2, respectively. As in delay discounting, if a participant was inconsistent in responding, h values were estimated by calculating the midpoint between their first and last consistent choice. If a participant did not become consistent at any stage of responding, i.e. their responding appeared random, they were excluded from further analysis.

Order presented	Smaller-certain reward	Larger probabilistic reward	probability	h at indiff.	h rank	Magnitude subscale
1	£20	£80	0.1	0.33	1	small
11	£40	£100	0.18	0.33	1	medium
21	£40	£60	0.4	0.33	1	large
2	£20	£80	0.13	0.45	2	small
12	£40	£100	0.22	0.42	2	medium
22	£40	£60	0.46	0.43	2	large
3	£20	£80	1.17	0.61	3	small
13	£40	£100	0.29	0.62	3	medium
23	£40	£60	0.55	0.61	3	large
4	£20	£80	0.2	0.75	4	small
14	£40	£100	0.33	0.74	4	medium
24	£40	£60	0.6	0.75	4	large
5	£20	£80	0.25	1	5	small
15	£40	£100	0.4	1	5	medium
25	£40	£60	0.67	1.01	5	large
6	£20	£80	0.33	1.48	6	small
16	£40	£100	0.5	1.5	6	medium
26	£40	£60	0.75	1.5	6	large
7	£20	£80	0.5	3	7	small
17	£40	£100	0.67	3.04	7	medium
27	£40	£60	0.86	3.07	7	large
28	£40	£60	0.92	5.75	8	small
18	£40	£100	0.8	6	8	medium
8	£20	£80	0.67	6.09	8	large
9	£20	£80	0.75	9	9	small
19	£40	£100	0.86	9.21	9	medium
29	£40	£60	0.95	9.5	9	large
10	£20	£80	0.83	14.65	10	small
20	£40	£100	0.91	15.17	10	medium
30	£40	£60	0.97	16.17	10	large

Table 2.2: shows items from Madden, Petry & Bickel (2009) questionnaire ranked by h value. "Order presented" shows numerical order items appeared in questionnaire; "probability" shows the probability of large reward receipt; "h at indifference" shows the value of discount rate at which small certain reward and larger probabilistic reward are equal in subjective value according to hyperbolic function (equation 2 in general introduction), "h rank" shows items with the same h grouped. "Magnitude subscale" shows which subscale items belonged to according to reward size.

2.3.4: Alcohol Use Questionnaire (AUQ; Mehrabian and Russell, 1978; Townshend & Duka, 2002):

Participants were asked to estimate the frequency and quantity of alcoholic drinks they consume (see appendix 1: 1.4). The questionnaire provides two measures of alcohol consumption: the AUQ and Binge scores. The AUQ score assesses patterns of drinking and drinking frequency,

whereas the binge score assesses how often participants consume alcohol in order to be intoxicated, their speed of drinking and how often they have been drunk recently. The binge score is also used to identify binge and non-binge drinkers; those with a "binge score" in the top 33% of the sample were classified as "binge drinkers" and those with a binge score in the lowest 33% were classified as "non-bingers", in line with Townsend and Duka (2005) those scores that made up the final third were deemed "unclassifiable". In the original Townsend and Duka (2005) methodology, a score ≤16 was classified a "non-binger" and a score ≥ 24 was classified as a "binger".

2.3.5: Drug Use Questionnaire (DUQ) (Morgan, 1999; Nesic & Duka, 2006):

This self –report measure was used to establish the rate and frequency with which participants have experimented with abusive drugs, we used an extended version of a DUQ, developed in our laboratory (Nesic & Duka, 2006; see appendix 1: 1.5). The questionnaire lists a number of more commonly abused of illicit substances including MDMA, cannabis and amphetamines as well as a number of less frequently abused drugs such as alkyl nitrite inhalants (poppers) and nitrous oxide (laughing gas, nos). Participants were asked to indicate the estimated duration, frequency of drug use and the average quantity of dose consumed per session. Cigarette smoking was established and analysed separately in the medical health questionnaire. This questionnaire was analysed by computing the total drug score which is calculated differently for THC and non-THC containing drugs- classifications for drug use can been seen in table 2.3 (taken from Nesic, Duka, Rusted & Jackson, 2011).

score	Non-THC based drugs	THC containing drugs
0	Never used	Never smoked
1	Not used in the last 30 days	Not smoked in the last 30 days
2	Used once in the last 30 days	Smoked once in the last 30 days
3	Used 2-5 times in the last 30 days	Smoked once a week in the last 30 days
4	Used 6-10 times in the last 30 days	Smoked several times a week in the last 30 days
5	Used 10+ times in the last 30 days	Smoked every day in the last 30 days

Table 2.3: shows the classifications of drug use

2.3.6: Medical History Questionnaire:

The medical history questionnaire asks for age, smoking status, current medication, about recent dentist and doctor appointments, height and weight. See Appendix 1:1.6 for questionnaire.

2.3.7: The Subjective Effects Visual Analogue Scale (VAS):

The VASs were presented on screen using e-prime. The Likert-type scale was used to assess the changes in mood brought about by behavioural paradigms. VASs were also used to assess Evaluative conditioning (liking) of reward cues, estimated duration of computerized tasks and awareness of cue-reward contingencies.

3. The effect of reward contingency and devaluation on sign- and goal-tracking in rats

Abstract:

Conditioned cues have been shown to influence behaviour by acquiring motivational properties; this effect can be observed using sign- and goal-tracking procedures. The propensity with which such stimuli can come to effect behaviour is influenced by a number of factors. Sixteen male Lister Hooded rats were used to examine the effect of manipulanda, satiety-induced devaluation and reward probability on the development and maintenance of sign- and goal-tracking responses. In accordance with previous research, reward uncertainty was associated with an increase in sign-directed responding, irrespective of conditioned response classification. Pre-exposure to either food or sucrose pellets induced non-specific reductions in responding, which was more pronounced for goal-directed responses than sign-directed responses.

Keywords: autoshaping, sign- and goal-tracking, reward contingency, manipulandum, devaluation

Current understanding of addiction posits that drug-associated stimuli contribute substantially to the expression of maladaptive behaviours such as compulsive drug use and relapse (Everitt & Robbins, 2005; Corbit & Janak, 2007). Through repeated exposure, these stimuli (CSs) are thought to form conditioned associations with the subjective experience of the drug (US); thus, the incentive salience attributed to the drug becomes generalised to contiguous environmental cues (Robinson & Berridge, 1993). The neurobiological pathways which have been rendered sensitive by the drug are now also stimulated by the previously inconsequential cues. This means the cues alone elicit drug craving and seeking; thereby, galvanizing compulsive behaviours (Robinson & Berridge 1993; Bevins & Palmatier, 2004).

In animal models, the influence of such conditioned stimuli (CS) on behaviour can be observed using Pavlovian conditioning. Such paradigms typically present a stimulus within a close temporal proximity to a reward (US); through repeated exposure, the CS comes to modify and shape the subject's behaviour (Wasserman & Miller, 1997) by acquiring motivational significance rendering

them "motivational magnets" (Robinson & Berridge 2008). This alteration in behaviour can be expressed in any number of ways (as observed by Skinner (1948) with superstitious behaviour) and is termed the *conditioned response* (CR) (Bevins & Palmatier, 2004). Research into the mechanisms by which the CS exerts influence over the conditioned response has produced contradictory results; in some cases, CSs appear to selectively prime for a particular reward; elevating the conditioned response associated with that reward only (Overmier & Lawry, 1979; Kruse, Overmier, Konz, & Rokke,. 1983). Conversely, other evidence suggests that the influence of the CS is more generalized; indiscriminately increasing arousal and appetitive responding (Rescorla & Solomon, 1967).

Evidence that reward paired stimuli have a strong influence over drug-seeking behaviour can be observed in *autoshaping* paradigms, in which the presentation of the rewarding US is independent of any CR (Tomie, Aguado, Pohorecky & Benjamin, 2000). The term "autoshaping", coined by Brown and Jenkins (1968), refers to how an individual comes to track a stimulus paired with reward (Parkinson et al., 2002); the repeated CS-US pairings used in such methodologies lead, in the majority of subjects, to the attainment of complex CRs directed at either the CS (Brown & Jenkins 1968; Tomie, Brooks & Zito, 1989) or the site of US delivery (Boakes, 1977). Autoshaping paradigms have been carried out in a variety of species including ring doves (Graf, Balsam, & Silver, 1985), quail (Burns & Domjan, 2000), cod (Nilsson, Kristiansen, Fosseidengen, Fernö, & van den Bos, 2008), pigeons (Tomie, 1981), and rats (Tomie et al., 1998) using a variety of localizable CSs, including levers (Atnip, 1977; Davey, Oakley & Cleland, 1981; Locurto, Terrace & Gibbon, 1976), static lamps (Holland, 1980) and restrained conspecifics (Timberlake, 1983; Timberlake & Grant, 1975). Results from autoshaping paradigms have reliably observed individual differences in CR topography. The explanation for this variation is thought to be based on how incentive salience is attributed to the CS and site of reward delivery (DiFeliceantonio & Berridge, 2012; Flagel, Akil & Robinson, 2009) as, generally, conditioned response topography can be defined in terms of stimuli- or goal-directed behaviours.

Stimulus directed behaviour, known as *sign-tracking*, is typically defined in terms of CS approach responses, followed by CS-directed appetitive responding such as chewing, licking, and grabbing (Davey, Cleland & Oakley, 1982; Tomie et al., 1989; Hearst & Jenkins, 1974; Poplawsky & Phillips 1986). The second kind of conditioned response is directed at the site of reward delivery and is known as *goal-tracking*, animals exhibiting such a response will not approach the reward-predictive cue, but upon its presentation will move towards the location of reward delivery

(Boakes, 1977). While the majority of animals can be described in terms of sign- or goal-directed CRs, there is a proportion of animals that will oscillate in their responses and appear ambivalent to both the CS and US (Flagel, Watson, Robinson & Akil, 2008).

While sign- and goal-trackers differ in a number of dimensions, the resultant CRs both lack the adaptability of instrumental learning and are thought to be under Pavlovian control (Parkinson et al., 2002). However, sign-tracking topographies show evidence for being more reflexive than goal-tracking and, once triggered by the CS, difficult to restrain or control (Tomie, 1996). Sign-trackers have also been shown to find the CS alone an effective reinforcer and will work to gain access to it (Robinson & Flagel, 2009). These differences are thought to be due to sign-trackers attributing incentive salience to the cue, whereas goal-trackers attribute it to the goal (Meyer et al., 2012). This assertion is further supported by the observation that sign-directed responding is resistant to satiety induced devaluation (Cleland & Davey, 1982) and devaluation of reward using lithium chloride (taste aversion; Morrison, Bamkole, & Nicola, 2015; Nasser, Chen, Fiscella, & Calu, 2015) suggesting that, for sign-trackers, the motivational value of the cue is distinct from the value of the outcome. Sign-tracking CRs have also been observed to be more resistant to Pavlovian extinction than goal tracking responses (Beckmann & Chow, 2015; Ahrens et al., 2016) and to undergo, what appears to be, rapid reacquisition and spontaneous recovery (Tomie, Hayden & Biehl, 1980; Tomie, Rhor-Stafford & Schwam, 1981; Rescorla, 2005). These effects show remarkable similarities to behaviour observed in drug abuse (Tomie, 1995; 1996; Tomie & Kruse 1980) indicating that Pavlovian autoshaping responses, particularly sign-tracking, could potentially account for a number of key features of the drug abuse syndrome. For this reason, it is crucial to define how the CS and US can influence drug seeking and craving, for the advancement of treatments for drug abuse (Corbit & Janak, 2007).

Previous research has indicated that sign- and goal-tracking CRs can be influenced by a number of factors. Anderson and Spear (2011) hypothesized that age of testing would be crucial to the acquisition of conditioned responding (Adriani & Laviola, 2003). As drug experimentation is prevalent in adolescence (SAMHSA, 2008), it was hypothesized that responding would differ between animals that experienced drugs or drug cues early or later in development. The results showed that early experience elicited more sign-tracking behaviours than exposure in adulthood. However, these sign-tracking responses developed over time, indicating that autoshaped responses emerge as a result of experience (Anderson & Spear 2011).

Nevertheless, some intrinsic traits are highly correlated with autoshaping conditioned responses. Research has indicated that high locomotor activity is associated with the advent of sign-tracking,

as opposed to goal-tracking (Flagel et al., 2009). Although, in studies using outbred animals there has been little evidence of such an association (Flagel et al., 2009). Therefore, it has been suggested that selectively breeding for locomotor activity also selected for other traits, such as impulsivity (Tomie et al., 1998) as sign-tracking responses showed a strong positive correlation with impulsivity measures (Belin, Mar, Dalley, Robbins, & Everitt, 2008). Furthermore, environmental enrichment, known to reduce impulsivity, also reduces the expression of sign- but increases the expression of goal-tracking responses (Beckmann, Marusich, Gipson, & Bardo, 2011; Wood, Siegel & Rebec, 2006).

Until recently, the most frequently used criterion for designating individuals as sign- or goal- trackers was the rank-order-split" which involved splitting the sample into thirds based on absolute number of conditioned responses, .e.g. lever presses, and designating the highest responders as sign-trackers and the lowest as goal-trackers (Bedard, Maheux, Levesque, & Samaha, 2011; Flagel, Watson, Akil, & Robinson, 2008; Robinson, Anselme, Fischer, & Berridge, 2014; Robinson & Flagel, 2009; Saunders & Robinson, 2010).

A shortcoming of this method is that it is based on the assumption that every sample contains an equal number of sign- and goal-trackers and, furthermore, might lead to the misclassification. In addition, the rank order split method is applied to a single action, usually lever pressing, and therefore fails to account for other behaviours such as orienting or approach which can more readily be applied to goal-tracking behaviours (Meyer et al., 2012).

One method of circumventing these issues was presented by Davey, Oakley, & Cleland, (1981) and involved allocating animals as sign- or goal- trackers by coding behaviour using predetermined topographic classifications. In their original paper Davey et al. (1981) classified subjects lever contacts with their left/right or both paws, nose, whiskers, tongue, teeth and chin. One potential fault with such a means of allocation is that, similar to the rank order split, these behaviours are solely in response to the cue and do not include goal-directed actions; in order to be able to distinguish animals that are high responders and animals that are sign-tracking, a measure of goal-directed responses must also be included.

A standardized means of classifying individuals was established by Meyer *et al, (*2012) called the *Pavlovian conditioned approach* index (PCA index). The PCA index aims to quantify and summarise the three properties of a Pavlovian stimulus, that is their ability to bias attention, motivate (become 'wanted') and induce a motivational reward-seeking state (Bindra, 1974; Toates, 1986; Berridge & Robinson, 2003), on a scale from -1 to +1; wherein, an index of 0 indicates an intermediate responder, -1 a strong goal-tracker and 1 being a sign-tracker (Meyer et al, 2012). In order to do this, the PCA index compares the ratio of

head entries to lever presses (response bias, equation 3.1), the difference in probability in making a goal- or signal-directed response (probability difference, equation 3.2) and the latency until a subject makes a goal or signal directed response (latency score, equation 3.3). These 3 values are averaged to produce a PCA score; this is done over multiple sessions (usually the last three) and then the PCA scores are averaged to produce the PCA index (equation 3.4).

$$Response\ Bias = \frac{(Lever\ presses - head\ entries)}{(Lever\ presses + head\ entries)}$$

Equation 3.1

$$Probability\ difference = probability\ of\ a\ lever\ press - probability\ of\ a\ head\ entry$$

Equation 3.2

$$Latency\ Score = \frac{average\ latency\ until\ head\ entry - average\ latency\ until\ lever\ press}{duration\ of\ CS\ period}$$

Equation 3.3

These values are then used to calculate the PCA scores, the equation for which is shown below (where x refers to any given test session), and then the PCA index is calculated by averaging the PCA scores for the last two days of training:

$$PCA\ score = \frac{Response\ bias_x + Latency\ Score_x + probability\ difference_x}{3}$$

Equation 3.4

Non–human animal research has shown that incentive salience is attributed more readily to ambiguous CSs than certain ones, even if the cue is distal to the site of reward delivery, (Robinson, Anselme, Fischer & Berridge, 2014). Such an effect might be attributable to an increase in frustration (Esber & Haselgrove, 2011) or, to anticipation such that the probabilistic element of a cue serves to increase the utility of the reward by "extend[ing] the otherwise fleeting benefit provided by consumption" (Loewenstein, 1987; p. 672). Conditioned response topographies have been shown to be differentially effected by probability of reward receipt (Anselme, Robinson & Berridge, 2013); wherein sign-tracking responses are potentiated by increased uncertainty but goal-tracking responses are diminished (Davey, Cleland & Oakley, 1981; Davey & Cleland, 1982). Further to this, recent research has shown that the effect of

uncertainty is similar to amphetamine sensitization by potentiating sign-tacking responses (Robinson, Anselme, Suchomel & Berridge; 2015).

Further evidence that autoshaped conditioned responses are extremely sensitive to interference can be observed in other studies that have shown a significant effect of drug type (Oscos, Martinez & McGaugh, 1988; Palmatier & Bevins, 2007), reward type (Davey & Cleland 1982; Davey et al., 1984; Timberlake, 1983,Wilkie & McDonald 1978), cue location (Brown & Jenkins 1968), stress (Beckmann & Bardo, 2012), the nature of the CS (Cleland & Davey 1983; Grastyán & Vereczkei 1974; Hearst & Jenkins, 1974; Davol, Steinhauer & Lee, 1977; Bilbrey & Winokur, 1973) and early cue experience (Davey, Cleland, Oakley & Jacobs, 1984) on the development of an autoshaping conditioned response.

A significant, and largely unaddressed, problem in research into sign- and goal-tracking is that the methodologies used to train such conditioned responses are not standardized. For example, within research using a retractable lever as a CS there is huge variety including one lever (Carroll & Lac, 1993; Tomie et al., 2000), nose poking for one lever (Anderson & Spear, 2011), two levers (Corbit & Janak, 2007; Davey & Cleland, 1982) and 3 levers (Robinson, Anselme, Fischer & Berridge, 2014). In fact, very few autoshaping procedures using a lever as the CS actually offer a control lever alternative, making it very difficult to compare the development of sign- or goal-tracking across studies. As it is already clear that sign- and goal-tracking responses can be significantly influenced by small procedural differences, we cannot assume that CR differences observed in one lever experiments are generalizable to procedures offering two levers.

There are three key aims to this experiment:

Firstly, to establish whether exposure to a single rewarding lever versus two levers, one rewarding and one control, influences the advent of sign- or goal- directed responses. Previous research using a one lever design has shown that a one lever procedure will produce sign-, goal- and intermediate responders in equal proportion (Flagel et al., 2009; Saunders &Robinson, 2010). In contrast, a two lever methodology by Holland (1989) produced only the sign and not the ambivalent or goal-directed CRs. As a consequence, it is predicted that when a two-lever condition is used, the topography of CR will be restricted to sign-tracking but that the one lever condition will produce sign- and goal-tracking responses.

Secondly, to examine the effect of reward contingency on conditioned responses, with a particular focus on whether this differs across conditioned response groups (intermediates, sign and goal-trackers).

Third and finally, to investigate whether intermediates, sign- and goal-trackers are differentially effected by devaluation of an appetitive reward by pre-exposure. If the assertion that sign-trackers differ from goal-trackers in how they attribute incentive salience is correct, then the CRs should be differentially affected by such a manipulation.

3.2: Method:

3.2.1: Subjects:

The subjects were sixteen male Lister Hooded rats, housed in standard plastic and stainless steel cages in a climate controlled facility (temperature: mean= 21.3^{0}C, max= 21.5^{0}C, min= 21.1^{0}C. Relative humidity: mean= 45.5%, max= 49%, min= 42.5%) with a same-sex littermate. The rats were maintained on a food restricted diet, water was available *ad libitum,* and 24 hour light/dark (12hr/12hr) cycle was maintained for the duration of the study. The procedures were conducted in accordance with the UK 1986 Animals (Scientific Procedures) Act 9 (project licence PPL 707072).

3.2.2: Apparatus:

The experiment was conducted in a set of eight standard MedAssociates plexiglass conditioning chambers (L: 30.5 cm x W: 24.1 cm x H: 21.0 cm), with stainless steel bar floors. Each chamber was enclosed in a ventilated, sound-attenuated box. Each chamber was equipped with two Colbourn levers (d: 1.5 cm x w: 5 cm) which were situated 1cm down and 3.5 cm from the left and right of the reward receptacle. The receptacle (w: 3cm x h: 4cm x d:~2cm) contained an infra-red beam that recorded head-entries. The reward was a single Noyes 45mg sucrose pellet (UK) delivered by a Colbourn pellet dispenser and, therefore, reward deliveries were associated with the brief click the food dispenser.

A computer running MET-PC-IV was interfaced with the chambers and recorded *lever presses (reward paired,* and for the 2 lever condition, *control), head entries into the receptacle* and *time with head in the receptacle.*

All equipment was wiped with 70% ethanol between sessions and cleaned with fragrance free soap and water between days.

3.2.3: Design

The rats were be split into two groups: the 1-lever group (rats 1-8) and the 2-lever group (rats 9-16). The experiment was a (2 x 2) mixed measures design. The dependent variables were *lever responses*, *head entries* and *time spent in the receptacle*. The independent variables were the lever group (1-lever and 2-levers) and conditioned response classification (intermediate, sign- and goal-tracker) and the repeated measures variable was devaluation condition (food or sucrose pellets). Acquisition of the conditioned behaviour is shown by an increase in dependent variables across conditioning sessions. Extinction is shown by a decline in all appetitive behaviours across sessions.

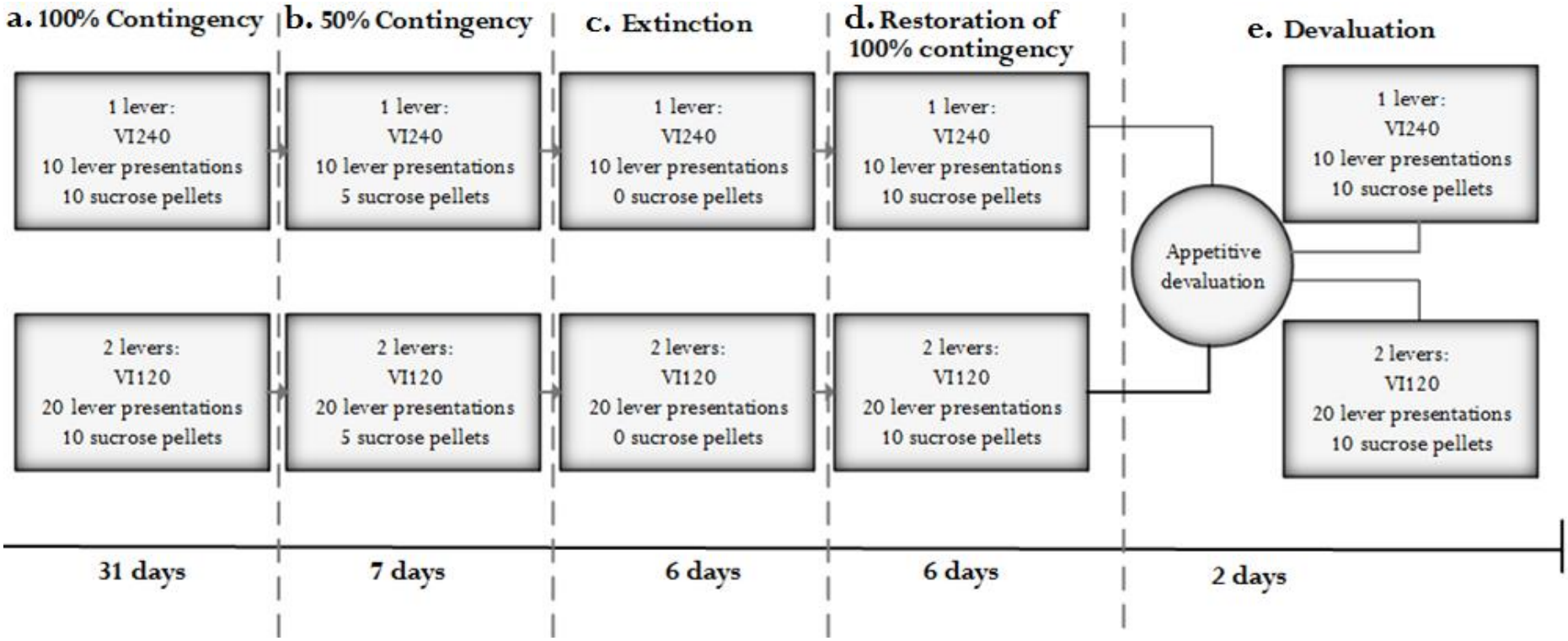


Figure 3.1: shows the stages of the experimental procedure split by lever condition

3.2.4: Procedure:

In order to reduce expressions of neophobia, the rats undertook 4 brief (30 minute) receptacle approach training sessions across 4 days before the experiment began. In this training, rats were placed in the chambers with the pellet dispenser activated on a RI30 schedule [min=15seconds, max=45seconds] set to deliver a single pellet into the receptacle. At the beginning of each session the magazine was also baited with 3 sucrose pellets.

Following magazine training, the experiment was split into five stages: conditioning 100% and 50% contingency, extinction, restoration of 100% contingency and devaluation.

3.2.4.1: Stage 1: conditioning (100% contingency)

Animals were then split into two independent groups: rats 1-8 were in the 1-lever condition and rats 9-16 were allocated in the 2-lever condition and the following conditioning stage took place over 31 days (see figure 3.1.a). It is important to note at this point that in both conditions rewards occurred entirely independently of any response by the animal. The levers are designated as "reward-paired" or "control". Subjects completed one session per day so, in order to eliminate time of day effects, running order was reversed daily.

For the 1-lever group, the reward-paired lever was presented on a variable interval schedule. The sessions lasted 40 minutes and the active lever (counterbalanced as front or back of chamber across animals) was presented on average every 240 seconds (min: 120 max: 360). The lever was presented for 8 seconds in the chamber and its retraction was paired with the delivery of a single sucrose pellet. In total, the 1-lever group received 10 sucrose pellets and lever presentations per session.

For the 2-lever group, the session was also 40 minutes but a second lever was also presented at the same probability. This meant that in this condition the average time between any lever presentation was 120 seconds (min: 60 max: 180). However, only 1-lever was paired with reward, making the contingency of reward-paired lever presentation the same across both lever conditions (average 240 seconds, min: 120 max: 360). Thus, the 2-lever group received 10 sucrose pellets and 20 lever presentations per session.

3.2.4.2: Stage 2: conditioning (50% contingency)

In order to assess the robustness of the CR across goal- and sign-trackers animals were placed on a 50% contingency schedule for 7 days (see figure 3.1.b). At this stage of the experiment, all

presentations remained the same as before but only 50% of the reward-paired lever presentations were followed by sucrose. For both conditions the number of sucrose pellets received per session dropped to 5.

3.2.4.3: Stage 3: extinction

During the 6 extinction sessions, the sucrose pellets were removed from the pellet dispensers. The animals were run on the same schedule as in training but no sucrose pellets were given during the 40 minute sessions (see figure 3.1.c).

3.2.4.4.: Stage 4: restoration of 100% contingency:

In order to see if the goal or sign-tracking response was more susceptible to renewal, both groups were entered back in the original training schedule used in conditioning for 6 days (see figure 3.1.d).

3.2.4.5: Stage 5: devaluation

The final stage of this experiment was designed to assess whether the goal- and sign-tracking response was more robust to appetitive devaluation. This was a repeated measures condition and took place over two days (see figure 3.1.e).

On both days a dish was filled with 40g of either 45mg Noyes sucrose pellets or 45mg Noyes food pellets. The dishes were then placed in back of the home cages (middle or left but avoiding where subjects seemed to designate as a "toilet area"). The rats were then given 45 minutes of free feeding during which they were undisturbed except for randomly timed ~30sec observations by the experimenter. After the 45 minute free feeding interval was completed the dishes were removed and 5 minutes later the animals were tested using the same procedure described in stage 1: 100% conditioning.

The food the animal was given for the free feeding period was counterbalanced across days those who received sucrose on day 1 (1-lever group: 1,2,7,8 2-lever group: 9, 10, 15, 16) received food pellets on day 2 and *vice versa*.

3.3: Results

3.3.1: Preliminary Analysis:

As the training protocol during 100% contingency was extensive (see Figure 3.1.a, 3.1.b) rather than including all the sessions in analyses, the data from 3 sessions were collapsed at the beginning

(*beginning phase:* 1,2 and 4), middle (*middle phase:* 19, 20 and 21) and end (*end phase:* 35, 36 and 37). Likeweise, analyses of stage 2, 50% contingencyperformance, data were collapsed for sessions 1 and 2 (*beginning phase),* sessions 3-5 (*middle phase),* and sessions 6and 7 (*end phase).* This method allowed us to observe how behaviour was maintained throughout training as previous research has shown that CRs develop over training (Anderson &Spear, 2011).

3.3.2: the effect of manipulandum on sign- and goal-directed responses

The first aim of this experiment was to assess the advent of sign- and goal- tracking conditioned responding as a result of manipulandum exposure. In order to do this two mixed ANOVAs were conducted to examine the proportion of responses directed at the cue (lever presses) and the goal (head entries magazine) across lever conditions (1 or 2 levers) and during the three phases (beginning, middle and end) of the 100 and 50% reward contingency stages.

3.3.2.1: Stage 1: Conditioning at 100% reward contingency:

There was a significant main effect of lever group, F (1, 14) =89.82, p<.001, partial η^2=.87; subjects in the one lever condition (M=48.15, SE=0.99) completed significantly more responses than those in the two lever condition (M=34.86, SE=0.99).

As hypothesized, there was a significant difference in responding across the three phases of 100% conditioning (beginning, middle and end), F (2, 28) =13.96, p<.001, partial η^2=.49. Analysis of the means showed that irrespective of lever condition responding increased from the beginning (M=36.20, SE=1.60) to the middle (M=43.17, SE=0.96) and end phases (M=45.14, SE=1.07).

There was a significant interaction between phase of 100% conditioning training (beginning, middle or end) and lever group, F (2, 28) =7.79, p=.001, partial η^2=.41. Analysis of the means shows that while subjects in the one lever condition completed more lever presses (M=53.28, SE=4.88) than head entries (M=43.02, SE=5.09), the reverse is true for those in the two lever condition (lever presses: M=28.74, SE=4.88; head entries: M=40.98, SE=4.88).

3.3.2.2: Stage 2: Conditioning at 50% reward contingency

There was a significant main effect of lever group, F (1, 14) =22.29, p=.005, partial η^2=.45; subjects in the one lever condition (M=49.92, SE=1.58) completed significantly more responses

than those in the two lever condition (*M*=42.40, *SE*=1.58). There was also a significant interaction between lever group and response (lever press or head entry), *F* (1.07, 15.03) =5.26, *p*=.035, partial η^2=.27. As in 100% contingency training, those in the one lever condition completed more lever presses (*M*=71.63, *SE*=9.57) than head entries (*M*=28.20, *SE*=9.86) whereas, those in the two lever condition completed more head entries (*M*=45.59, *SE*=9.57) than lever presses (*M*=39.22, *SE*=9.57).

The proportion of goal and cue directed responses completed by each lever group (one and two) were then compared across all contingency stages (100, 50, 0 and restoration of 100%) but revealed no significant differences.

3.3.3: the effect of contingency on sign- and goal-directed responses

The second aim of this experiment was to assess the effect of reward contingency on sign- and goal- directed responding. In order to assess this, the end phase of 100% contingency training was used as baseline for comparison to the other contingency stages, the proportion of responses directed to the cue or the magazine were then compared.

3.3.3. 1: stage analysis (using end of 100% conditioning and collapsed 50% training).

There was a significant interaction between experimental stage and response, *F* (3, 45)= 33.62, *p*<.001, partial η^2=.69. Subjects completed significantly more lever presses during the 0% contingency stage than during the 100% and restoration of 100% (*ps*<.001) and 50% (*p*=.001) contingency stages (see figure 3.2). Whereas, subjects completed significantly fewer head entries during the 0% contingency stage than during the 100% and restoration of 100% (*ps*<.001) and 50% (*p*=.002) contingency stages (see figure 3.2)

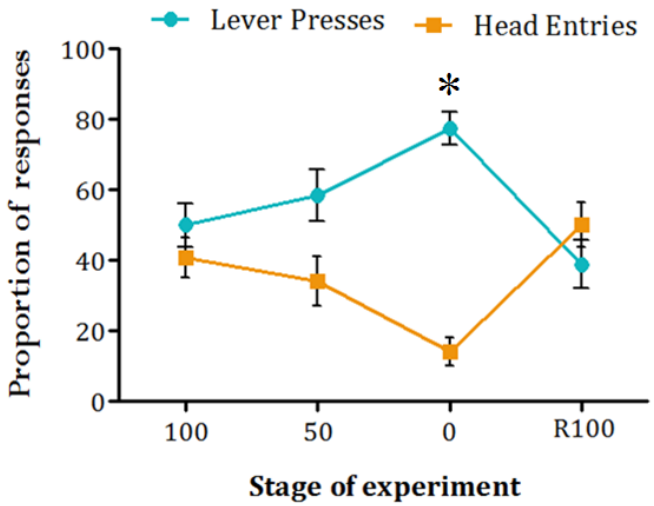


Figure 3.2 shows mean difference in proportion of behavioural responses across the end phase of 100% contingency stage (100), 50% (50), 0 (unreinforced) and restoration of 100% contingency (R100) (error bars show ± SE; asterisks denote significant difference between response within stage)

3.3.4: the effect of devaluation on sign- and goal-directed responses

The final aim of this experiment was to ascertain whether sign- or goal-directed responding was differentially effected by devaluation of an appetitive reward by pre-exposure. Two repeated measures ANOVAs were used to examine the effect of reward devaluation on the proportion of and actual number of head entries and lever presses compared to the final session of restoration of 100% contingency, referred to as baseline.

There was a significant difference in the proportion of sign and goal directed responses, F (1, 15) = 4.86, p=.043, partial η^2=.25; irrespective of stage, a higher proportion of responses were lever presses (M=62.02%, SE=5.45) than head entries (M=37.98%, SE=5.45).

There was a significant different stage by response interaction, F (2, 30) = 13.67, p<.001, partial η^2=.48. Further analysis revealed that there was a significant increase in the percentage of lever presses during the maintained (p<.001) and devaluation stages (p=.001) compared to baseline (see figure 3.9A). Conversely, there was a significant decrease in the proportion of head entries during the maintained (p<.001) and devalued stages (p=.001) compared to baseline (see figure 3.3A).

A two way ANOVA was then used to compare changes in actual response rates, the results showed that there was a significant decline in response rates across stages, F (2,15)=31.08,

$p<.001$, partial $\eta^2=.67$). Subjects responded significantly more at baseline ($M=30.59$, $SE=3.14$) compared to the devalued ($M=13.16$, $SE=2.01$, $p<.001$) and maintained stages ($M=10.91$, $SE=1.42$, $p<.001$).

There was also a significant interaction between stage and response, F (1.29, 19.36) = 9.45, $p=.004$, partial $\eta^2=.39$. Further analysis revealed that, compared to baseline, there was a significant decline in head entries during devalued ($p=.001$) and maintained stages ($p<.001$) (see Figure 3.3B); however, there were no significant difference to number of lever presses.

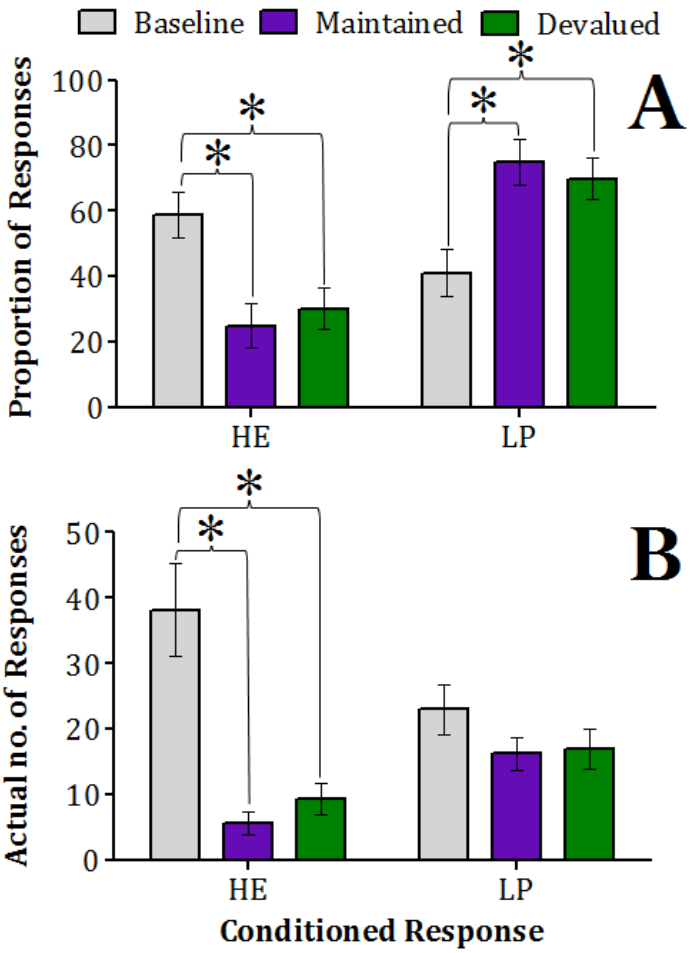


Figure 3.3 **(A)** shows mean difference in proportion of behavioural responses **(B)** shows mean difference in actual responses directed to either the reward magazine (HE) or the active lever (LP) at baseline (the final day of the restoration to 100% contingency stage) compared to the devalued and maintained stages (error bars show ± SE; asterisks denote significant differences)

3.3.5: categorisation of individuals as intermediates, sign- and goal-trackers

In addition to a programming fault preventing the latency score being calculated, the results of the trial by trial data were also corrupted. This meant that the probability difference across trials could also not be calculated. As a consequence, the PCA score could not be used to classify animals as sign-, goal- or intermediate trackers. In order to avoid misclassification by using the rank order split, animals were classified using the response bias alone (equation 3.1) averaged across the last 2 days of stage 1: 100% contingency training. Subjects were then classified according to benchmarks used by Meyer, Cogan and Robinson (2014) for designation on the basis of PCA index; animals with a response bias of 0.4 or higher were classed as "sign-trackers" and less than -0.4 as "goal-trackers". Animals with response biases ranging from 0.39 to -0.39 were classed as "intermediates". According to these criteria, rats 1, 5, 6, 7 and 12 were sign-trackers, 8, 13 and 16 were goal trackers and 2,3,4,9,10,11,14 and 15 were intermediates. Intermediate trackers were excluded from further analysis; however, as the Ns of the goal-and sign-tracking response groups were small, further analysis is descriptive.

In addition, for 50% of the animals (four from the 1-lever condition [2, 3, 4 & 5] and five from the 2-lever condition [10, 11, 12, 13 & 15. Rat 15 was later excluded as portions of video data were obscured]) video data were analysed and behaviours in the 8 seconds of lever insertion and 8 seconds following lever retraction were recorded. As training was protracted, 10 sessions were coded from the 100% contingency block (*see figure 3.1.A*). Behaviour was classified using predetermined topographic classifications (*see table 3.1)* similar to those used by Davey et al. (1981). However, in addition to the manual and oral responses, attempted contact with the levers was recorded as was orienting to both the cue and magazine, which has previously been used as a measure for sign-and goal-tracking in rats (Olshavsky et al., 2015). These actions can be broadly designated into lever (sign-tracking) and magazine (goal-tracking) directed actions (see table 3.1) and were converted into proportion of total observed behaviours. Video coding and response bias classification showed 75% agreement in designation.

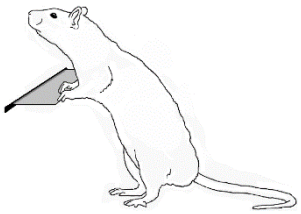
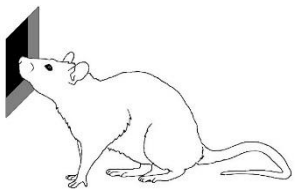
8 second period:	During lever insertion	Following lever retraction
Lever (rewarding & control) 	• Orienting • Contacting with paw • Oral behaviour (licking, small nibbling movements, biting)	• Orienting • Head entries into magazine
Magazine 	• Orienting • Attempted contact with paw • Attempted oral behaviour	• Orienting • Head entries into magazine

Table 3.1: shows the definitions of lever and magazine directed actions used to code the video footage of the two 8-second periods during and following lever insertion

3.3.5.1: The effect of reward contingency on sign- and goal-tracker responding

In sign-tracking subjects, as reward contingency decreased the proportion of responses directed towards the cue (lever presses) increased. Conversely, for goal-tracking animals the proportion of cue directed responses decreased in the second block (50% contingency) but increased dramatically when the reward contingency dropped to zero (see table 3.2). Interestingly, for both sign-and goal- trackers the restoration of 100% contingency led to a drop in cue directed response rates. Goal-directed behaviours performed by sign-trackers decreased as reward contingency decreased from 50-0%; however, with the restoration of 100% contingency, lever pressing comprised the majority of responses. For goal-trackers, the drop from 100 to 50% contingency led to an initial increase in goal-directed responding but when reward contingency dropped to zero the percentage of goal directed responses also decreased. In contrast to sign-trackers, when the reward contingency returned to 100% this led to a higher proportion of goal-directed responses by goal-trackers than had been completed in any previous contingency block.

	Percentage of total responses			
	Sign-Tracker		Goal-Tracker	
	M	*SE*	*M*	*SE*
Lever Press				
100%	77.56	4.5	17.38	2.27
50%	83.61	7.16	14.85	0.28
0%	91.09	5.16	54.44	6.66
R 100%	57.68	13.89	8.80	1.65
Head Entries				
100%	18.8	4.50	76.22	4.51
50%	13.46	7.34	80.48	2.96
0%	4.76	4.39	33.27	12.39
R 100%	34.99	14.25	81.23	0.70

Table 3.2: average proportion of responses directed at the cue and the goal by sign- (n=5) and goal-trackers (n=3) across contingency blocks (100, 50, 0 and restoration of 100% contingency).

3.3.5.2: The effect of reward devaluation on sign- and goal-tracker responding

The effect of reward devaluation on sign- and goal-directed responding was then examined across sign- and goal-tracker designations. Figure 3.4A shows that irrespective of classification, the proportion of sign-directed responses was lower at baseline (final day of restoration of 100% contingency) than after devaluation and maintained sessions. Examination of figure 3.4B and 3.4C shows that total actual response rates were higher in the goal-tracking animals than the sign-tracking animals. In both sign-trackers (3.4B) and goal-trackers (3.4C) the number of head entries decreased after pre-feeding but lever pressing did not change. The proportion (3.4A) and actual number (3.4C) of responses that were sign-directed by goal-trackers shows that devaluation by pre-exposure to the reward reduced the lever pressing compared to the maintained condition. Conversely, for sign-trackers the percentage (3.4A) and absolute number (3.4C) of lever presses are very similar after maintained and devalued sessions.

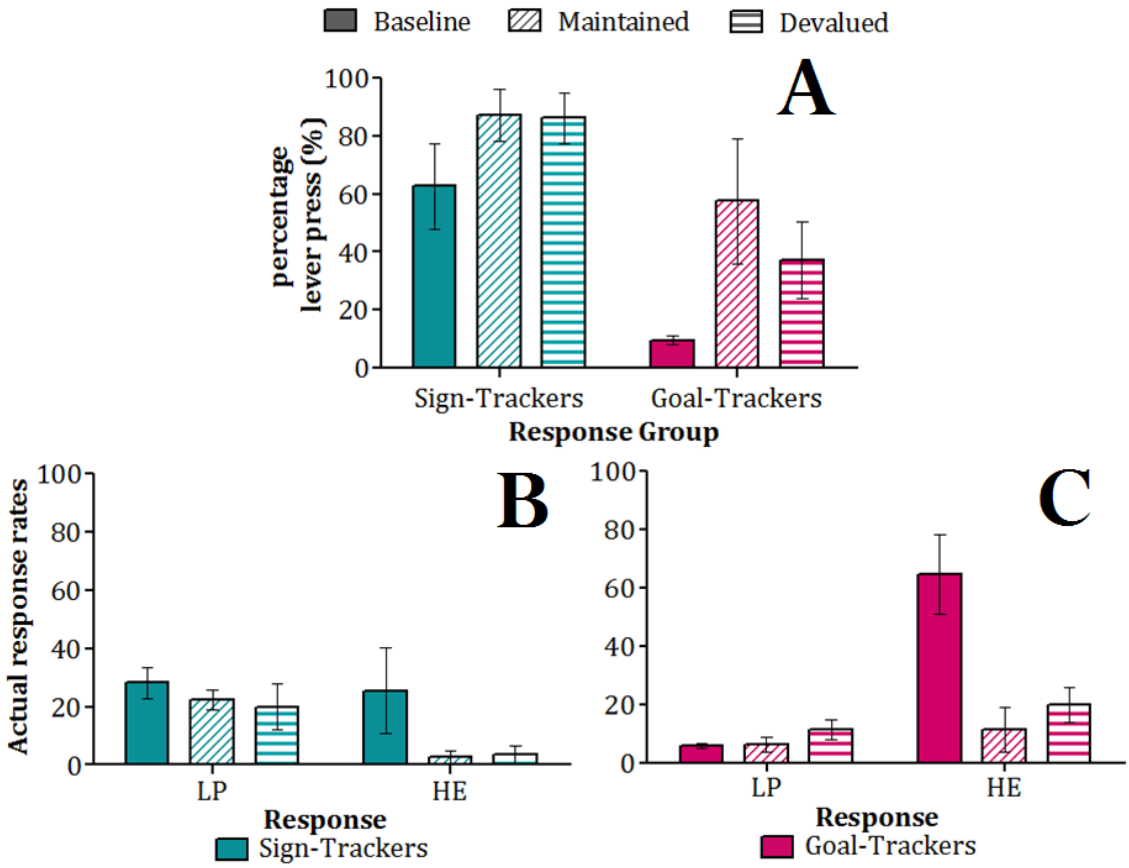


Figure 3.4: **(A)** shows proportion of lever presses by sign- and goal-trackers **(B)** shows actual number of behavioural responses by sign-trackers and **(C)** shows actual number of behavioural responses by goal-trackers directed to either the reward magazine (HE) or the active lever (LP) at baseline (the final day of the restoration to 100% contingency stage) compared to the devalued and maintained stages (error bars show ± SE)

3.4: Discussion

The first aim of this study was to establish whether exposure to a single rewarding lever or two levers, one rewarding and one control, influences the advent of conditioned response topographies (intermediates, sign and goal-trackers). Although the results from this study failed to show the predicted acquisition of conditioned response topography, that the one lever protocol would produce sign-, goal- and intermediate responders in roughly equal proportion (Flagel et al., 2009; Saunders &Robinson, 2010) whereas the two lever method would produce only sign-trackers (Holland, 1989), a difference in propensity to develop a sign- or goal- directed CR as a result of manipulanda does seem to exist. One possible reason for the disparity between our 1-

lever and 2-lever groups is that sign-tracking will only happen if the hedonic conditioning CS is established enough to compete with the US (Costa & Boakes, 2009). It is possible that in our experiment the use of a second lever diminished the incentive salience attributed to it as a cue, reducing the effect of the CS response compared to the US response.

This explanation might also serve to explain why, in so many autoshaping experiments, the goal-tracking topography fails to emerge. Unlike the lever, the reward receptacle is constantly exposed meaning that goal-tracking can occur at any point; whereas, the lever is inserted intermittently so sign-tracking can only occur sporadically (Farwell & Ayres 1979). The method suggested by the PCA index, of comparing the lever responses during the time the lever is exposed, for example 8 seconds, with the head entries that occur into the magazine in the equal amount of time following its retraction, i.e. 8 seconds, allows for a more accurate designation compared to the rank order split by making the two responses more comparable. Alternatively, the methodology could be changed so that the reward receptacle becomes available for the same duration as the lever as was done by Brown and Jenkins (1968) in their original experiment.

Another potential explanation for the differences observed between our 1-lever and 2-lever group was raised by Skinner (1948) when discussing superstitious behaviour in the pigeon; he noted that the inter-trial interval was a key factor in the rate of acquisition and the nature of the response observed in pigeons. The results from this study show that the 1-lever group, with the longer ITI, showed more sign-tracking behaviours; it is possible that the long ITI created a sense of anticipation which increased general behaviour. It has previously been asserted that the irrational behaviour, such as that seen in sign-tracking, of "wanting" a reward more than one likes it, is produced by decision utility exceeding predicted or remembered utility (Berridge & Aldridge, 2008; Berridge, 2012). Previous research has demonstrated that increasing reward uncertainty potentiates sign-, but not goal-racking responses (Anselme, Robinson & Berridge, 2013; stage 2 and 3 of the current investigation). In the current protocol a higher proportion of animals in the 1 lever condition developed the sign-tracking typography than the 2 lever condition. One possible explanation for this is that the task duration was maintained across lever conditions but, as the number of presentations in the 2 lever group was twice that on the single lever group, the inter-trial interval was double the length in the 1 lever condition (VI240) to the 2 lever (VI120). Therefore, in order to ascertain that the advent of sign-tracking was the result of manipulanda and not uncertainty inflating decision utility, it would be beneficial to replicate the experiment with a third condition wherein 2 levers are presented but the inter-trial interval matches that used in the 1 lever condition (VI240). One of the main problems in sign-tracking research that has been identified by this experiment is that methodologies using one lever are not comparable to procedures using two. The results of this

study indicate a significant effect of group meaning that whether the animal is presented with one lever or two levers will influence their propensity to exhibit sign- or goal-tracking responses. This result compounds the assertion that sign- and goal-tracking responses are very sensitive to influence by procedural variation. The very nature of the CS has been shown to have a significant impact on the acquisition of autoshaped behaviours. A study by Cleland and Davey (1983) showed a differential effect of auditory and visual CSs on sign and goal-tracking responses leading them to suggest that how ecologically relevant a cue is to an animal will influence the acquisition of reward seeking behaviour (Cleland & Davey, 1983). In this study the cue used to induce sign-tracking was the insertion of the lever itself; this could be considered a compound cue, as it is both visual and auditory. It is possible that as the lever was both an auditory and visual stimuli is will have more influence over behaviour than the magazine which was only visual and does not move; further supporting the methodology of only briefly exposing the magazine in a similar way to lever insertion.

The second aim was to explore the relationship between reward contingency and the strength of conditioned responses, with a particular focus on whether this differs across conditioned response groups (intermediates, sign and goal-trackers). In accordance with existing research, results from the current experiment revealed that as the probability of reward receipt declined, response rates increased and the proportion of those responses directed towards the sign, over the goal, also increased (Robinson et al., 2014). While previous research has shown that uncertainty potentiates sign-tracking, but not goal-tracking (Davey et al., 1981; Davey & Cleland, 1982), results from the current analysis showed that, irrespective of conditioned response classification, goal-directed responses were positively correlated with the probability of reward receipt.

The third aim of this investigation was to investigate whether sign- and goal-directed behaviours are differentially effected by devaluation of an appetitive reward. If the assertion that sign-trackers differ from goal-trackers in how they attribute incentive salience is correct, then the conditioned responses should be differentially affected, as the value of the CS should be independent of the value of the outcome. Results of the devaluation manipulation revealed that after satiety-induced pre-exposure there was a reduction in goal-directed responses (head entries), irrespective of pre-exposure condition (food or sucrose pellets). Cue directed responses, lever presses, were slightly reduced in sign-trackers after pre-exposure to either food type but in goal-trackers this effect was more pronounced after the devaluation than maintained manipulation. Analysis also revealed that goal-directed responses were diminished more than lever presses by pre-exposure to appetitive

reinforcers, supporting the assertion that goal-directed responses are more sensitive to devaluation generally (Cleland & Davey, 1982; Morrison, Bamkole, & Nicola, 2015; Nasser, Chen, Fiscella, & Calu, 2015). The reinforcer-specific devaluation in the current experiment may have been limited by the small ns in each conditioned response group and the extensive training on a single reinforcer used earlier in the study (Holland, 2004). If this is so, then the extensive training at the outset of the experiment led to specific response-outcomes representations as opposed to a generalised motivational state, as might have been observed if multiple reinforcers were used or training had been shorter.

It should be noted here that an alternative method of assessing satiety-induced devaluation has been used by Johnson, Gallagher and Holland (2009) wherein animals were trained with two flavours of sucrose solution (grape and orange) one of which was devalued for half the animals and the other for the remaining half. Evidence suggests that training animals using multiple reinforcers reduced the effect of prolonged instrumental training on devaluation effects (Holland, 2004).

A problem with sign- and goal- tracking research that was discussed in the introduction is the criteria by which individuals are classified as a sign- or goal-trackers. A commonly used methodology is the rank-order-split, wherein rate of responding on the levers is split into thirds with the greatest responders being sign-trackers and the lowest responders being goal-trackers (Saunders and Robinson, 2010).However, this method is based on the assumption that every sample contains an equal number of sign- and goal-trackers; this produces variation in the benchmarks of sign- and goal-tracking designation across experiments which means that individuals who are labelled as one kind of responder may be excluded from another study's criteria. While the PCA index (Meyer et al., 2012) has reduced this cross-experiment variability by providing a standardised method of designating responders, the benchmarks used to assign individuals has varied across experiments from the original ± 0.53 to ± 1 (Meyer et al. 2012) to ± 0.3 to ± 1 (Yager & Robinson, 2012) and ± 0.4 to ± 1 (Meyer, Cogan & Robinson, 2014).

Another issue with sign and goal-tracking methodologies is that it has been illustrated that pre-exposure to cues slows the acquisition of sign and goal-tracking responses (Costa & Boakes, 2009). Whilst this would have little to no effect in studies with extensive conditioning periods like this one it might mean that in shorter studies CRs have not yet had time to fully develop at the time of testing. In order to address this, Tomie (1976) suggested that during magazine training the context in which the animal is trained is clattered in terms of its olfactory, tactile, auditory and visual cues; these changes are thought to reduce context blocking and aid relevant learning.

Chapter 3: sign- and goal-tracking in rats

- Sign- and goal-tracking topographies developed over the course of training
- Contrary to our initial hypothesis, the 1-lever condition produced a higher proportion of sign-trackers than other conditioned response groups and the 2-lever condition produced both sign-and goal-trackers
- Lowering reward contingency from 100-50% increased overall responding.
- Further reduction in reward contingency from diminished goal-tracking responding but potentiated sign-tracking responses
- Restoration of 100% had the reverse effect and increased goal-tracking responses and reduced sign-tracking responding
- Pre-exposure to food or sugar pellets caused response non-specific devaluation. Both goal- and sign-tracking responses were reduced but goal-tracking responses were more effected than sign-directed responses.
- There was limited descriptive evidence of reinforcer specific devaluation in the sign-directed responses in goal-trackers only, in line with previous research; however, N is too small for statistical analysis.

4. Sign- and goal-tracking in humans

Abstract:

The purpose of these experiments was to investigate sign- and goal-tracking behaviours in human participants using eye-tracking equipment. A novel procedure was utilised; images were presented, representing the cue and the goal, and paired with a 10pence reward at different contingencies. In experiment 4.1 (n=64) and experiment 4.3 (n=29) the probabilities were 10, 50 and 90% and in experiment 4.2 (n=32) they were 0 and 50%. In accordance with previous research using animals, three conditioned response topographies were identified, intermediates, sign- and goal-trackers, using the Pavlovian Conditioned Gaze (PCG) classification. Substance abuse, alcohol consumption and impulsivity, as measured by discounting rates and the Barratt Impulsivity Scale-11 (BIS-11), were compared across PCG classes and found to be non-significant.

Keywords: sign-tracking, goal-tracking, contingency, context, eye-tracker, impulsivity, discounting

Animals have an evolutionary imperative to learn associations between cues and rewards, to allow for direction of behaviour or anticipatory responses (Pavlov, 1927). This occurs through repeated pairings of the reward and cue so previously neutral stimuli can become imbibed with motivational properties; rendering them attractive and energizing (Robinson & Berridge 2001). Sensitized neural pathways are now stimulated by these once innocuous cues and can produce craving independently of reward (Bevins & Palmatier, 2004). Such stimuli have demonstrated to contribute to compulsive behaviours (Everitt & Robbins, 2005; Corbit & Janak, 2007). Therefore, this process is thought to be integral to understanding, and potentially preventing, drug relapse (Berridge, Robinson & Alridge, 2009).

Brown & Jenkins (1968) first reported the effect of localized signals on orienting, contact and approach behaviours, terming it *auto-shaping*. A key feature of autoshaped behaviours is that they occur when reward receipt is independent of behavioural response, i.e., non-contingent (Davey, Oakley & Cleland, 1981; Tomie, Di Poce, Derenzo & Pohorecky, 2002; Kearns, Gomez-

Serrano, Weiss & Riley, 2006). Non-human animal models demonstrate that the nature of the conditioned responses elicited by reward-paired cues is widely disparate (Flagel, Watson, Akil, & Robinson, 2008); when presented with a predicative cue, a subset of animals will approach and contact it (*sign-trackers)* (Tomie, Brooks & Zito, 1989), another will approach the site of reward delivery (*goal-trackers) (*Boakes, 1977; Flagel et al., 2011) and another vacillates between the two (*intermediates)* (Meyer et al., 2012). The value, or *utility,* of a reward can be broken down into remembered, predicated, experienced and decision utilities (Kahneman, Wakker & Sarin, 1997). The hedonic, subjective experience of a reward is *experienced utility* (Berridge & O'Doherty, 2014), the active reconstruction of past experienced utility is *remembered utility* (Berridge & Alridge, 2008). *Predicted utility* is an associative expectation of how liked a future reward will be and decision utility is, considering factors such as probability, of the potential value of the outcome at the point of making a decision (Berridge & Alridge, 2008). It has been suggested that decision utility reflects the incentive salience or "wanting" of a reward, whereas experienced utility describes liking (Berridge & O'Doherty, 2014); therefore, when we describe sign-trackers attributing incentive salience to a cue, what this means in utility terms is that on cue presentation there is a transient increase in decision utility so that is exceeds predicted/remembered utility, and it is this which produces the sign-directed behaviours (Berridge & Alridge, 2008). Sign-tracking behaviours have been compared to relapsing in drug abuse (Tomie, Grimes, & Pohorecky, 2008); in that previously reward paired cues can produce psychomotor activation or drug seeking, even after long periods of abstinence (Saunders & Robinson, 2010, 2011; Yager & Robinson, 2013). These individual differences are not the result of overall deficiencies in learning (Meyer et al., 2012) rather, differences in the propensity to attribute incentive salience to reward predictive stimuli (Lovic, Saunders, Yager & Robinson, 2011). Sign-trackers are thought to attribute incentive salience to the cue (Olhavsky et al., 2014), which means that, for a sign-tracker, a reward predictive cue alone can act as a conditioned reinforcer but this is not true for goal-trackers (Robinson & Flagel, 2009).

One factor known to effect incentive salience attribution is the probability of reward receipt after cue onset. A possible explanation for this, according to Mackintosh (1975), is that the probability of reinforcement on presentation of a stimulus is positively correlated with attention that stimulus receives. Brown and Jenkins (1968) suggested that conditioned responses are resultant of a positive correlation between cue presentation and a biologically salient event; the reasoning being, the more reliable a cue in predicting reward, the more distinctive one can expect it to be (Griffiths & Mitchell, 2008) increasing its associability (Le Pelley & McLaren, 2003).

Conversely, an increase in uncertainty produces an increase the attribution of incentive salience to reward paired cues, even to distal stimuli (Robinson, Anselme, Fischer & Berridge, 2014). This finding can be explained by the Pearce-Hall model of attention which posits that a stimulus will be imbued with more attention the more uncertain it is (Pearce & Hall, 1980); therefore, the higher the prediction error, the more attention the cue receives. Esber and Haselgrove (2011) suggested that uncertain rewards could hold attention more than certain rewards if omissions increased overall reinforcer value, and that this might occur by increasing frustration or anticipation. This would mean that emotional associability, over uncertainty, is integral to attentional processes (Esber & Haselgrove, 2011; Bindra, 1969; Robinson & Berridge, 1993).

In keeping with these theoretical ideas and earlier research by Davey and colleagues (Davey, Cleland & Oakley, 1981; Davey & Cleland, 1982), recent findings demonstrate that sign- and goal-tracking responses are differentially effected by probability of reward receipt; uncertainty has been shown to potentiate a sign-tracking, but not goal-tracking (Anselme et al., 2013; Robinson, Anselme, Suchomel & Berridge; 2015). Robinson et al.'s (2015) experiment compared conditioned responses made for a variable reward by amphetamine sensitized, stressed or control animals in a Pavlovian sign-tracking procedure with two levels of probability: 100% US-CS association or 50% US-CS; results showed that sign-tracking responses were equally potentiated by uncertainty and amphetamine sensitization.

Furthermore, sign-tracking conditioned responses have been shown to be more readily reinstated by reward paired cues and more resistant to extinction than goal-tracking responses (Saunders & Robinson, 2010; Yager & Robinson, 2010). This has led to the assertion that the sign-tracking phenotype represents a more impulsive form of responding (Tomie, 1996; Lovic et al., 2011). Olshavsky et al. (2015) found that sign-tracking rats engaged in more risk-taking behavior than goal-tracking rats. Similarly, Beckmann, Marusich, Gipson & Bardo, (2011) observed that sign-tracking rats were more novelty seeking, and self-administered higher quantities of cocaine, than goal-trackers. Sign-tracking, but not goal-tracking, responses are sensitized by pre-exposure to amphetamine (Doremus-Fitzwater & Spear, 2011) and to predict a tendency towards alcohol consumption in rats (Anderson & Spear, 2011) and mice (Cunningham & Patel, 2007); although the nature of this relationship is inconsistent, as ethanol consumption has also been shown to potentiate goal-tracking behaviours (Krank, 2003; Krank, O'Neill, Squarey & Jacob, 2008).

While a propensity towards carrying out a sign- or goal-tracking conditioned responses has been suggested to be an indicator of susceptibility to drug use (Tunstall & Kearns, 2015; Robinson, Yager, Cogan, & Saunders, 2014), there is little or no convincing evidence for sign-tracking and goal-tracking in humans (Deckner, Wilcox, Miasto & Blanton, 1980; Siegel, 1977).

Both Pithers (1985) and Wilcove & Miller (1974) demonstrated sign-tracking in humans. Participants had access to a lever and, independently of any participant action, 1 or 2¢ (respectively) would be delivered into a tray, however, neither experiment included a measure of goal-directed responding. Results from a follow on assessment by Wilcove and Miller suggested that participants were using their lever responses as a means of hypothesis testing, which led the authors to conclude that the response differed from that shown in non-human animals. Newman, Wolff and Hearst (1980) demonstrated sign-tracking in university students while examining feature positive effects, the finding that learning is more rapid when a single distinguishing feature is paired with reward rather than presented in its absence. Whilst conducting their experiments, Newman et al. found that as the experiment progressed participants were increasingly likely to touch the positive cues, even though the response would not influence reinforcement, which the authors suggested was to render the stimuli more distinctive, aiding discrimination. Recently Garofalo and di Pellegrino (2015) examined sign- and goal-tracking using an eye tracker and were able to reliably discriminate between response groups based on dwell time. Which is particularly interesting as this outcome measure is very similar to the work of Olshavsky et al., (2014) who have used orienting as a conditioned response to measure sign- and goal- tracking in rats. Dwell time, i.e., the duration an individual spends looking at something, is an established measure of attention (Wills, Lavric, Croft, & Hodgson, 2007), and while attention can be shifted without moving one's eyes, in general the two are thought to be intrinsically related (Deubel & Schneider, 1996; Le Pelley, Beesley, & Griffiths, 2011). Thus, a benefit of using eye tracking equipment is that it allows for the examination of attentional models and how reward probability influences the impact a cue has on behaviour; as, the conditioned response topography shown by an individual could be resultant of where their attention is directed.

In addition to this, though not reported by Garofalo & di Pellegrino (2015), eye trackers can be used to measure of fixation count, i.e. the frequency with which one's eyes cease moving within a specific space, and run count, i.e. the frequency with which the gaze moves into a specific area; which together could be used to assess the nature of the conditioned response topographies.

The aim of this series of experiments is to attempt to identify intermediate, sign- and goal-trackers within a human population using an eye-tracker. Garofalo & di Pellegrino (2015) provided evidence that such groups could be distinguished using dwell time; by including additional behavioural measures these experiments aimed to further characterize the differences between the behavioural groups.

Animal models of sign- and goal-tracking have reported that sign-tracking increases, and goal-tracking declines, as probability of reward receipt decreases (Anselme et al., 2013). Previous research by our lab has produced mixed results; some indicating that the stimuli with the highest probability of being paired with reward will be the most attention grabbing (Austin & Duka, 2010). Alternatively, the most uncertain reward has also been shown to capture attention most readily (Trick, Lee & Duka, 2011).

By using an eye-tracker to examine sign- and goal-tracking, these experiments aimed to be the first to establish whether sign- or goal-tracking in humans is affected by changes in reward contingency. The animal literature outlined a number of areas in which sign and goal-trackers differ, these experiments explored the relationship between self-reported impulsivity, binge drinking, choice impulsivity (discounting), drug-use and eye-tracking responses.

4.2: Experiment 4.1

4.3: Method

4.3.1: Participants:

Sixty-four healthy participants (32 female) took part in this experiment. Ages ranged between 18 and 33 years (M= 21.20, SE=0.38; female: M=21.06, SE=0.44, Male: M=21.34, SE= 0.64). Neither age nor average BMI (M=22.03, SE= 0.58) differed significantly across counterbalancing conditions or sex. See General Methods for recruitment techniques.

4.3.2: Materials:

Participants were asked to complete the medical history questionnaire, Barratt Impulsivity Scale (BIS-11), alcohol-use questionnaire (AUQ), Kirby, Petry & Bickel (1999) delay-discounting

questionnaire, and drug-use questionnaire (DUQ), as described in the General Methods, which were presented on paper.

All procedures were programmed using Experiment Builder software (SR Research Ltd.; Ontario, Canada). The four stimuli used throughout the experiment (see Figure 4.1) were black shapes presented on a grey background and using a 20" Dell P1130 CRT computer monitor. Participant responses were collected using a keyboard and mouse.

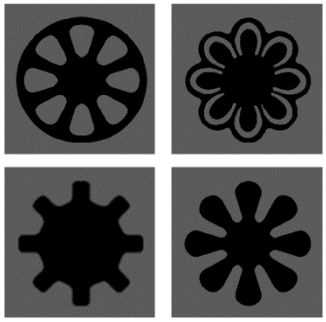


Figure 4.1: shows the images used throughout the experiment to represent the goal, CS90, CS50 and CS10 stimuli

Eye-tracking was conducted using an Eyelink II eye-tracker (SR-Research Ltd.; Ontario, Canada). The participant's position was assessed using infrared light emitters, mounted on the monitor, providing feedback on head location to an infrared camera mounted on the head strap. The position of the right pupil was sampled at a rate of 500Hz by another infrared camera, mounted below the eye on an adjustable arm (see *figure 4.*2). At the beginning of each session the eye-tracker was calibrated by the experimenter, using a 3x3 grid; this was repeated between *blocks*. In addition, participants were required to complete a self-administered drift correction between trials: this involved pressing the spacebar whilst focussing on a small circle at the centre of the screen (shown in *figure 4.*3a). This procedure allows for reliable estimates of gaze position at the initiation of each trial (Cornelissen, Peters, & Palmer, 2002).

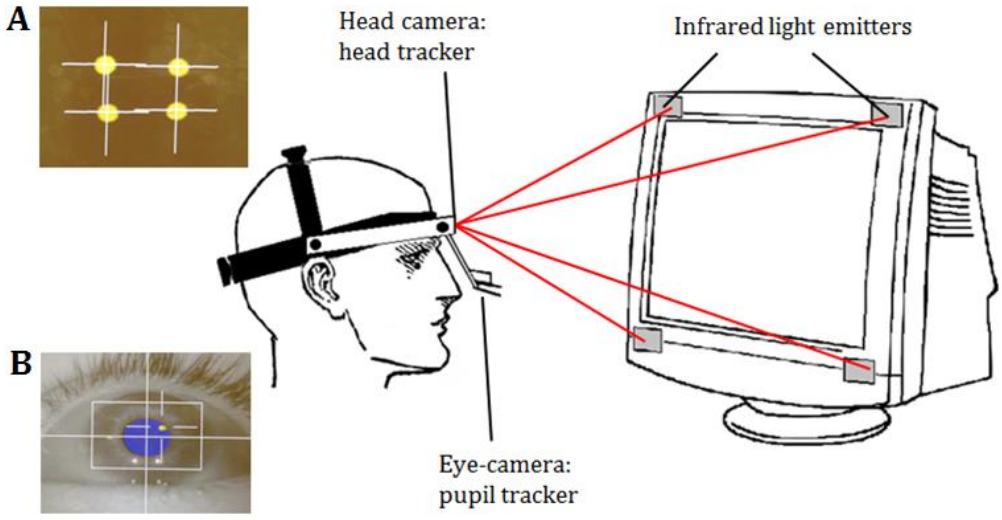


Figure 4.2: shows the feedback from the two infrared cameras, their location on the head-mounted apparatus and the location of the infrared light emitters on the CRT monitor **(A):** shows the feedback from the infrared-light emitters to the head-tracker and **(B)** shows the feedback from the eye-camera's pupil tracker.

4.3.3: Design:

This was a 3 (contingency: 90, 50, 10) by 2 (image: cue, goal) by 6 (block: 1,2,3,4,5,6) measures design. Images and goal and cue location were counterbalanced across conditions.

4.3.4: Procedure:

Participants were individually guided through each questionnaire and completion took approximately 30 mins. Participants were then taken to individual testing room where they completed the eye-tracking procedure, under the guise of it being a decision-making task. The program consisted of 180 trials, split into 6 blocks.

Each trial began with a drift correction (shown in *figure 4.*3a) after which two empty rectangles appeared on the screen. After 1000ms (shown in *figure 4.*3b), each rectangle was filled with an image (shown in *figure 4.*3c, *images* in *figure 4.*1) such that three of the four pictures shown in figure 1 appeared an equal number of times to cue reward delivery on 10% (CS10), 50% (CS50) or, 90% (CS90) of the trials. In the second rectangle, the same image (from *images* in *figure 4.*1) appeared on all trials and served as the goal-stimulus (left, right; counterbalanced) and written feedback about whether a trial was rewarded ("you have won 10p") or not ("you win nothing") was superimposed for 1000ms on the goal image at the end of each trial *(figure 4.*3d). Overall, the reward contingency for both the goal and *cue* stimuli was 50%. Both images remained on the screen for 4000ms (3000ms images alone + 1000ms images and feedback), followed by an

additional 1000ms during which no cues of feedback were present. Each block consisted of 30 trials, 10 trials of each contingency (CS10, CS50 and CS90). Randomization ensured that only two trials of the same reward probability could appear consecutively.

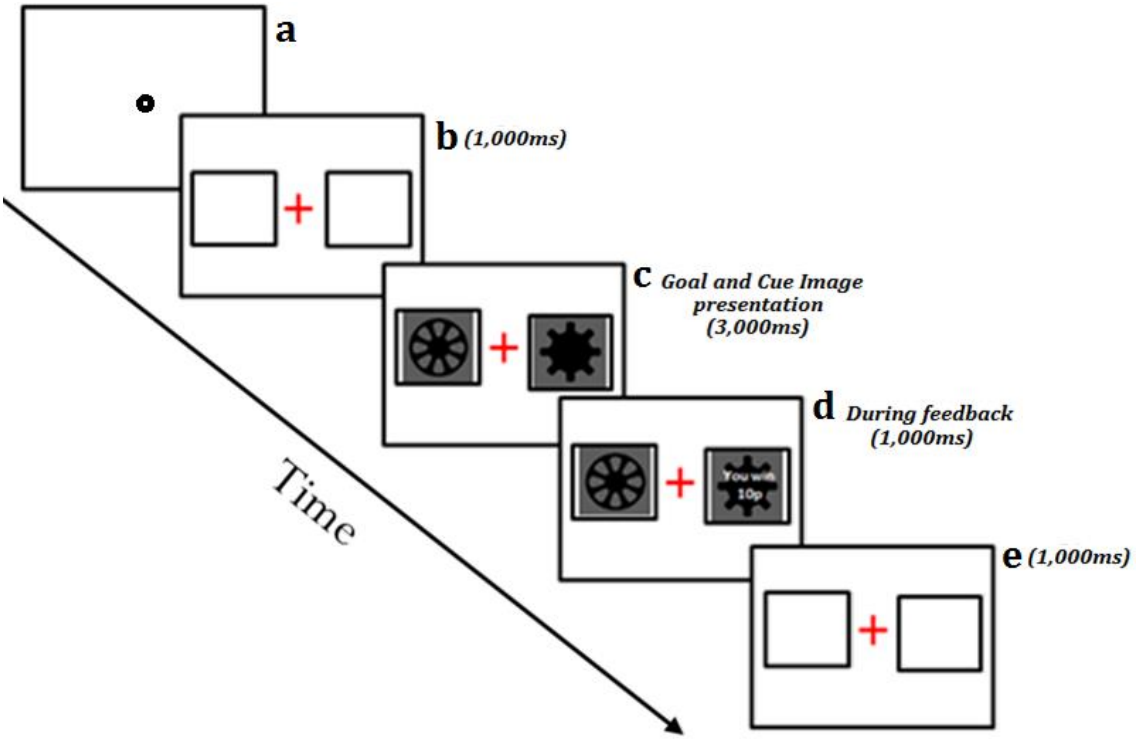


Figure 4.3: a reinforced trial sequence between drift corrects- location of *goal* and *images* counterbalanced across participants

Previous research indicates that awareness is essential for conditioning in humans (Field & Duka, 2001; Hogarth, Dickinson, Wright, Kouvaraki, & Duka, 2007); inclusion of contingency awareness is necessary in order to distinguish those who acquire the associations between cues and reward from those who do not. Conditioned response groups can then be compared for differences in awareness, so as to establish them as distinct from reward expectancy. Therefore, at the end of each block, participants completed a series of on-screen contingency awareness questions ("*how likely is it that this image will be followed by the reward?*": 0-100% VAS). In addition to this, preferences for stimuli are also thought, to a certain extent, to govern behaviour (De Houwer, Thomas & Baeyens, 2001) and to expedite acquisition of cue-reward associations (Hofman, Hower, Perugini, Baeyens & Crombez, 2010). Therefore, questions assessing evaluative conditioning were also included in order to assess evaluative conditioning ("*how anxious does this picture make you feel?"* and "*how pleasant do you find this picture?" Response scale 1-9)* and. On

completion of these questions the eye-tracker was recalibrated by the experimenter and the next *block* would begin.

4.3.5: Data Analysis:

Methods for analysing the *Barratt Impulsivity Scale-11 (BIS-11), Alcohol Use (AUQ), Drug Use (DUQ), Kirby et al., (1999) discounting* and *medical history* questionnaires are described in General Methods.

4.3.4.1: Eye-tracking measures:

Saccades were defined by the EyeLink software as beginning when eye velocity exceeds 30° per second or acceleration exceeds 8000 degrees per second squared. Saccade offset was defined when velocity / acceleration have returned below these two thresholds. Fixations are defined as samples which are not in saccades (or blinks). In other words, a fixation begins when the preceding saccade ends, and ends when the subsequent saccade begins (Stampe, 1993). *Figure 4.*4 illustrates the different eye-tracking measures derived from the raw data. These measures were collected and analysed from the 3,000ms period when both the cue and the goal were visible simultaneously, without any written feedback (Figure 4.3C).

Fixation count provided a measure of the number of times the eyes fixated within the *cue* or *goal,* irrespective of the duration of each fixation. *Dwell time* was calculated by summing the span of every fixation within the *goal* or *cue,* providing a measure of the time participants spent looking at each image and, therein, attention (Wills et al., 2007). *Run count* is the total number of times the gaze crosses the border, providing an indication as to whether one *image* was returned to at a higher frequency than the other. Additionally, we recorded the *latency* to fixate, on either the *goal* or *cue*, at the onset of a trial.

Figure 4.4: illustrates the measures *dwell time, fixation count* and *run count.* **A.** shows fixation count each green dot presents each time the gaze ceases and is counted equally, irrespective of the interval the fixation. **B.** shows dwell time, each cross represents a fixation with small crosses indicating short intervals and larger crosses showing longer durations (ms), all of which were summed. **C.** shows run count, each time the gazes moves in or out of the *image*, the red arrows would constitute a run of two, the blue a run count of one.

Research has reliably demonstrated an interplay between cognitive load (or effort) and pupil size (van Rijin, Dalenberg, Borset & Sprenger, 2012); with pupils typically increasing in size as the task becomes more challenging (Hyönä, Tommola & Alaja, 1994; Kahnemann, 2011).

Alternatively, it has been proposed that pupil dilation is influenced by emotion; the hypothesis being that pupils dilate in response to emotionally arousing stimuli compared to neutral cues (Partala & Surakka, 2003; Lang & Bradley, 2010). Use of the eye-tracker will allow for the examination of pupil size across sign- and goal-tracking groups, providing an objective measure of arousal. As the distance between the participants and the screen varied across individuals and trials, changes in pupil-diameter as a function of *goal*, *cue* and across *contingency* were calculated from an average pupil size baseline across all the fixations in the session.

4.3.4.2: Awareness:

Awareness classification (Field & Duka, 2001) was done using the averaged expectancy ratings of the CS10 and CS90, taken at the end of blocks 3- 6. *Aware* participants were those whose average rating for the CS90 was higher than 70 and for the CS10 was lower than 30. If participant's average ratings were between these bench-marks, their raw score ratings from blocks 3-6 were assessed for evidence of learning. In such an instance, participants were classed as *unaware* if their ratings for the CS90 and CS10 did not differ in the final block by 50 points.

4.3.4.3: Pavlovian conditioned gaze:

PCA index was calculated using dwell time, a table of values is available in appendix 2 (table 2.1). Dwell time was used for three reasons; firstly, dwell time is a measure of the amount of time looking at an image and has been termed a measure of attention (Wills et al., 2007). Secondly, Garofalo and di Pellegrino (2015) were able to discriminate sign- and goal-tracking using dwell time. Finally, Olshavsky et al (2014) use orienting behaviour as a measure of sign- and goal-tracking in rats. Thus, being able to classify individuals based on dwell time would be roughly translatable across species.

Participants were then allocated based on dwell times on *images*, into one of three classifications of Pavlovian Conditioned Gaze (PCG): *sign-tracker, goal-tracker* and *intermediate.* Dwell times on goal and cue were ranked based on duration and split into thirds: top, middle and bottom 33%. If a participant's dwell time was in the top 33% for the *cue* and the bottom 33% for the *goal,* they were designated a *sign-tracker.* If a participant was in the top 33% *goal,* and the bottom 33% *cue,* they were classified as a *goal-tracker.* All other participants were classified as *intermediate.* This

means that the *intermediates* encompassed those participants who spent an equal amount of time attending to the sign and goal images, irrespective of whether they were high and low responders. A table of smoker, binger, impulsivity and drug groups across PCG classifications is in appendix 2(Table 2.2).

Classification	Cue	Goal
Sign-tracker	Top 33%	Bottom 33%
Goal-tracker	Bottom 33%	Top 33%
Intermediate	Top 33%	Middle 33%
	Bottom 33%	Middle 33%
	Middle 33%	Top 33%
	Middle 33%	Bottom 33%

Table 4.1: designations of participants into responders, *sign-tracker, goal-tracker* and *intermediate,* using the Pavlovian Conditioned Gaze (PCG)

4.3.4.4: Corrections and statistics:

Greenhouse-Geisser and Huynh-Feldt corrections have been applied wherever Mauchley's test indicated that the assumption of sphericity had been violated. Partial eta squared (partial η^2) effect sizes have been included after each significant effect to aid interpretation. The benchmarks for partial η^2 are as follows: a value of 0.02 or larger indicates a small, between 0.13 and 0.26 denotes a medium, and in excess of 0.26 is a large effect (Cohen, 1988). Unless stated otherwise, all post-hocs performed used the Bonferroni correction.

4.4: Results:

To aid interpretation, the results are split into the following 2 sections: Section 1 explores whether *contingency* had a differential effect on eye-tracking measures across levels of *image (cue, goal)* and whether *awareness* influenced eye-tracking measures or evaluative conditioning ratings. Section 2 examines how PCG classifications interacted with *block, contingency,* and *awareness* classifications across eye-tracking measures and whether PCG classifications differed across questionnaire measures.

4.4.1: Section 1: Establishing measures.

4.4.1.1: Contingency:

3 way repeated measures ANOVAs were conducted to examine the main effect of *contingency* (10, 50 & 90%). There were no significant effects for fixation count, dwell time, run count, latency and pupil change data any measures (see table 2.3 in appendix 2).

4.4.1.2: The effect of contingency across images (goal, cues):

The interaction effect between contingency and image (goal and cue) were then examined. There were no significant main or interaction effects for the measure percentage change in pupil dilation. There was a significant main effect of *image* for fixation count (F (1, 63) = 7.85, p =.007, partial η^2= .11), dwell time (F (1, 63) = 7.17, p =.009, partial η^2= .10), Run Count (F (1, 63) =5.49, p =.022, partial η^2= .08) and latency (F (1, 63) =6.35, p =.014, partial η^2= .09); with participants showing a significant bias towards the cue *(*see *table 4.*1).

	Cue		Goal	
	M	*SE*	*M*	*SE*
Fixation Count	1.08	0.07	0.93	0.06
Dwell Time (ms)	217.21	16.35	160.48	12.62
Run Count	0.68	0.04	0.57	-.04
Latency (ms)	2109.98	46.69	2233.86	41.89

Table 4.2: shows the average (±SE) fixation count, dwell time, run count and latency split by *image*

There was a significant interaction between image and contingency for the variables, fixation count (F (1.69, 106.60) = 4.16, p =.025, partial η^2= .06, *figure 4.*5A), dwell time (F (1.78, 112.18) = 4.27, p =.020, partial η^2= .02, *figure 4.*5B), latency (F (1.55, 97.56) = 4.48, p =.023, partial η^2= .07, *figure 4.*5D) and run count (F (1.56, 98.44) = 5.40, p =.010, partial η^2= .08, *figure 4.*5C).

For goal image, participants showed the same pattern of responding across levels of contingency for fixation count, dwell time, run count and latency. Participants fixated, dwelt, completed more runs into and returned more rapidly (latency) to goal10 followed by goal50 and finally goal90. Significantly more fixations (p= .021) and runs (p= .021) were completed into the goal10

than the goal90 and significantly more fixations (p= .043) and runs (p= .030) were completed into the goal10 than the goal50 (see *figure 4.*5A and 2.5C)

For the cue, participants completed more fixations, completed more runs and were fastest to fixate at CS90 then CS50 and CS10. However, for the measure dwell time, contingency had a different effect and participants spent the longest duration dwelling on the CS50, followed by CS90 and then finally CS10; results showed the CS50 was dwelt on for significantly longer than the CS10 (see *figure 4.*5B).

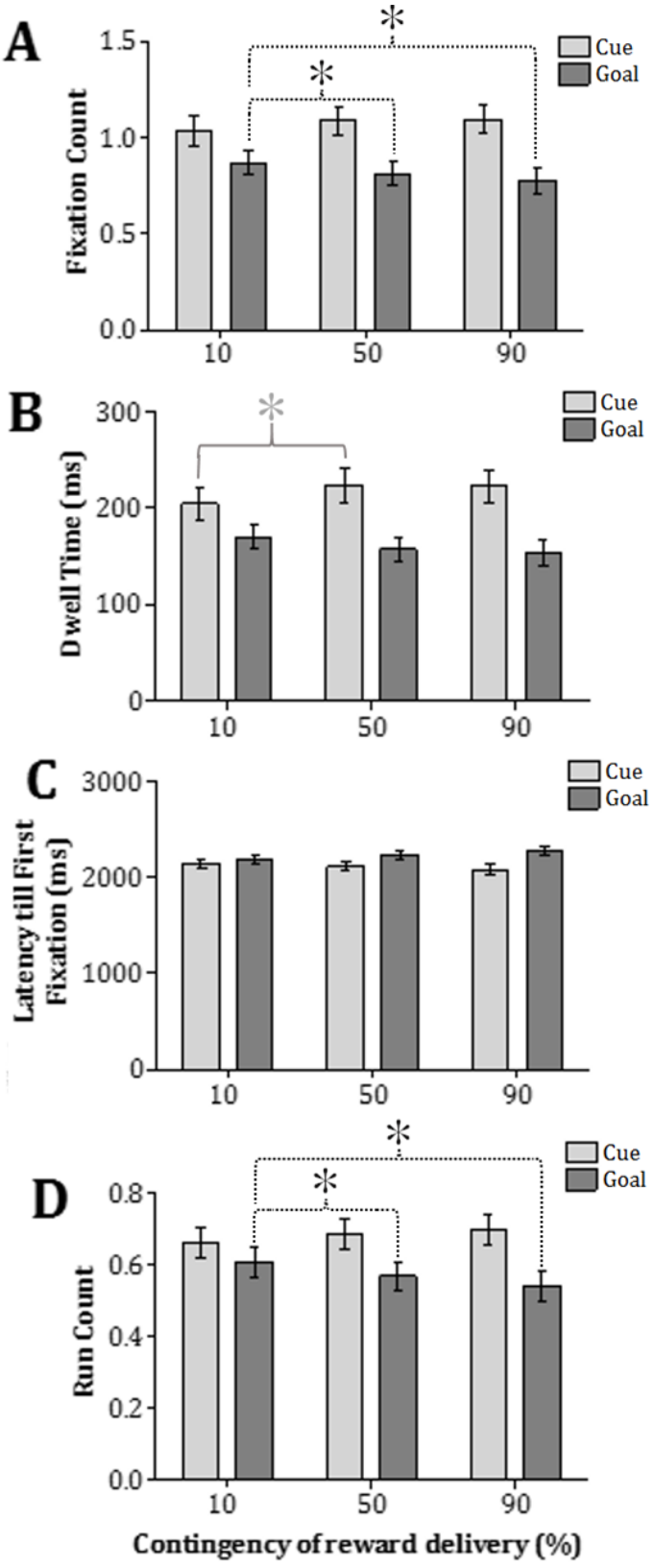


Figure 4.5: shows the interaction between *contingency* and *image* for average (± SE) fixation count **(A),** dwell time **(B),** latency **(C)** and run count **(D)** (dotted asterisks show significant differences across goal images, grey asterisks show significant differences across cue images).

4.4.1.3: Awareness

As the benchmarks for classifying individuals as aware or unaware were not taken from an existing study, the data were initially examined in order to ensure that those classified as aware and unaware were indeed significantly different behaviourally. A two way ANOVA revealed a significant effect of *stimulus (*CS10, CS50, CS90, goal) (F (3, 186) =62.72, p<.001, partial η^2= .50), *awareness, (F* (1, 62) =4.59, p =.036, partial η^2= .07) and a significant interaction between *awareness* and *stimulus, (F* (3, 186) =48.66, p <.001, partial η^2= .44). Examination of *figure 4.6* shows that unaware participants failed to discriminate between the four images, except for their rating of CS10 (M= 38.58, SE= 13.73) which was significantly lower than the *goal* (M= 50.96, SE= 14.77; p=.019). Conversely, aware participants' expectancy ratings varied in accordance with image contingencies; CS90 was rated highest followed by CS50 then finally CS10. Ratings of CS90 was significantly higher in aware than unaware participants (p<.001) and the reverse was true for CS10 (p<.001). In aware participants' only the rating of CS90 was significantly higher than CS10, t (39) =23.99, p<.001

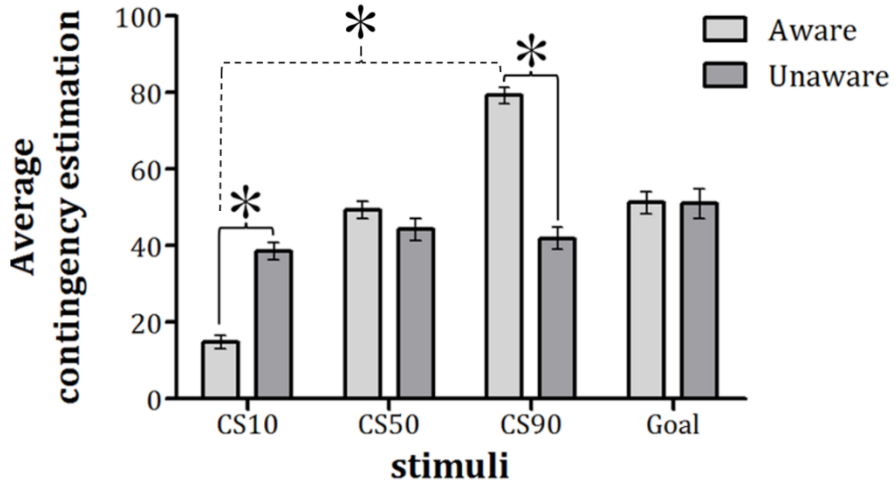


Figure 4.6: shows the contingency ratings of stimuli split by *awareness* classification (error bars: ± S.E) (significant differences denoted with asterisks: solid line between groups, dashed line within groups)

4.4.1.4: The effect of contingency awareness on eye-tracking measures:

Once it was established that *aware* participants had a superior knowledge of stimuli reward contingencies than *unaware* equivalents, it was important to ascertain whether *contingency awareness* influenced behaviour. Therefore, 2 way mixed ANOVAs were then conducted for each of the eye-tracking variables to examine *contingency* and *awareness*.

There were no significant interactions between contingency and awareness; however, awareness alone influenced behaviour. There was a significant effect of awareness on fixation count, F (1, 62) =4.50, p =.038, partial η^2= .07, run count, F (1, 62) =10.57, p =.002, partial η^2= .15 and latency, F (1, 62) =12.83, p =.001, partial η^2= .17. Table 4.3 shows that aware participants were significantly faster to complete their first fixation and completed significantly more fixations than unaware participants. Aware participants also had a significantly higher run count, meaning they returned to the goal or cue more frequently than their unaware counterparts.

	Fixation count		Run Count		Latency (ms)	
	M	*SE*	*M*	*SE*	*M*	*SE*
Aware	1.03	0.06	0.70	0.04	2077.92	42.85
Unaware	0.81	0.08	0.50	0.05	2328.58	55.33

Table 4.3: shows the average (±SE) latency till first fixation, fixation and run count on *images* (*goal, cue)* split by *awareness* classification.

4.4.1.5: The effect of awareness on evaluative conditioning:

A two way ANOVA was used to determine whether *pleasantness* and/or *anxiety* ratings of the stimuli, (cue10, cue50, cue90, and goal) differed across *awareness* classifications**.**

4.4.1.5.1: Pleasantness:

For pleasantness, there was a significant effect of stimuli (F (2.71, 168.27) =8.59, p<.001, partial η^2= .12, *awareness*, (F (1, 62) =7.48, p=.008, partial η^2= .11.) and a significant *contingency* by *awareness* interaction, (F (2.71, 168.27) =10.91, p<.001, partial η^2= .15). In terms of *awareness*, the *aware* (M= 4.92, SE= 0.18) found the images to be significantly more pleasant than *unaware* (M= 4.10, SE= 0.24). Analysis of *figure 4.*7A shows that in *aware* participants differentiated between the stimuli whereas the unaware participants did not. The aware participants rated the CS90 as significantly more pleasant than CS50 (p= .002), CS10 (p< .001) and the goal (p=.002); however, this is not true in unaware participants.

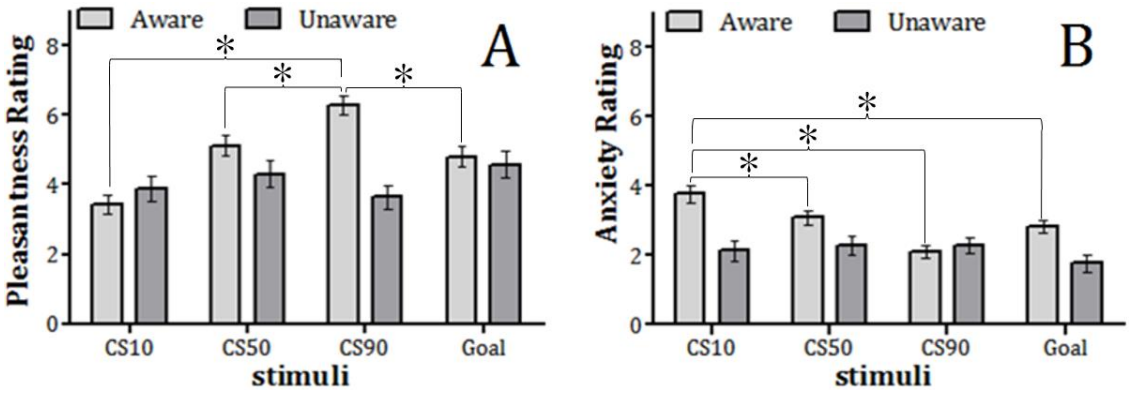


Figure 4.7: shows evaluative conditioning variables, *figure 4.*7**A**: pleasantness, 2.7**B**: anxiousness, split across *stimuli (*cue10, cue50, cue90 and goal) split by *awareness* classification (error bars show ± S.E) Asterisks denote significant differences in ratings within aware group.

4.4.1.5.2: Anxiety:

For anxiety there was a significant effect of stimuli (F (2.55, 158.08) =8.53, p<.001, partial η^2= .12), awareness (F (1, 62) =9.83, p=.003, partial η^2= .14) and a significant *contingency* and *awareness* interaction, (F (2.55, 158.08) =9.88, p<.001, partial η^2= .14). Anxiety ratings overall were significantly higher in *aware* (M= 2.96, SE= 0.16) than *unaware* participants (M= 1.13, SE= 0.21). Inspection of *figure 4.*7B shows that *aware* participants differentiated between the stimuli whereas *unaware* did not. *Aware* participants' anxiety ratings increased as contingency decreased; CS10 elicited significantly more anxiety than CS50 (p= .005*)* and CS90 (p= .003*).* Whereas *unaware* participants failed to discriminate between stimuli.

4.4.2: Section 2: Pavlovian Conditioned Gaze Classification (PCG):

According to the PCG, 8 participants were classified as *goal-trackers,* 17 were classified as *sign-trackers* and 39 were classified as *intermediate.* The aim of this section is to elucidate how these classifications differ behaviourally, in terms of their *awareness* and across questionnaire measures. As *PCG classification* was done on the basis of *dwell time* on the *cue* and *goal,* the behaviour of each group needs to be assessed using additional measures to ascertain whether the designations of *intermediate, goal* and *sign-tracker* reflect genuinely disparate response groups, within the sample, for all eye-tracking measures. Initially, the measures were assessed across the 6 blocks in order to examine acquisition (section 4.4.2.1); then variables were collapsed into a single measure (section 4.4.2.2).

The only eye-tracking measure that did not differentiate between the *PCG classifications* was percentage pupil dilation. There was a significant interaction between *image* and *block, F (*2.91, 151.15) =3.46, *p* =.019, partial η^2= .06. *Figure 4.*8 shows that in block 1, participants' pupils dilated when looking at the *cue,* and contracted when looking at the *goal.* However, as training continued this tendency changed and pupils dilated in response to the *goal* and contracted in response to the *cue.*

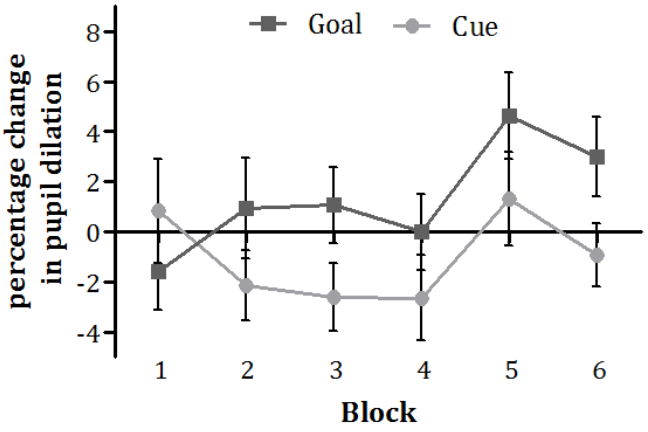


Figure 4.8: Average pupil dilation split by *image* across *blocks* (error bars show ± S.E)

4.4.2.1: Differences in eye-tracking measures between PCG classifications:

Here was a significant difference in overall fixations across *PCG classifications*, *F (2, 61)* =3.47, *p*= .037, partial η^2= .102. The average number of fixations by the *goal-trackers* and *sign-trackers* were similar (see *table 4.*3), but the *intermediate* group completed significantly fewer fixations than the *sign-trackers, (p*=.04). Total dwell times, i.e. on *cue* and *goal* together, differed significantly across *PCG classifications*, *F (2, 61)* =7.51, *p*<.001, partial η^2=.28. *Table 4.*4 shows that the total dwell time for the *sign* and *goal-trackers* was comparable, but the *intermediates'* total dwell time was significantly shorter than the *sign-trackers, (p*=.001).

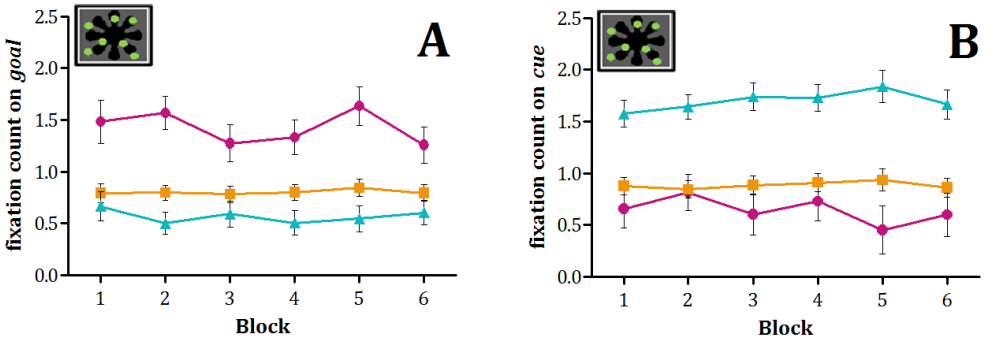
There was a significant *Image* by *PCG classification* interaction for fixation count (*F (1, 61)* =67.84 *p*< .001, partial η^2= .69), dwell time (*F (2, 305)* =92.98, *p*<.001, partial η^2=.75), latency (*F* (2, 61) =44.37, *p*<.001, partial η^2=.59) and run count (*F (2, 61)* =53.85 *p*< .001, partial η^2= .64). *Sign-trackers* were faster to fixate on, completed more runs into, fixated, and dwelt on the *cue* significantly more than the *goal* (*ps*<.001*);* whereas the reverse was true for the *goal-trackers* (*ps*<.001*).* The *intermediate* participants demonstrated minimal bias to either image in dwell time, fixation count or run count (*ps*<.100), but were significantly faster to fixate on the cue than the goal (*t* (38) =-2.31, *p*=.026).

Within *PCG classifications* bias in responding towards the *goal* or *cue* remains consistent across training *blocks,* as shown by *Figure 4.*9). Taken together, these results show participants who were classified as *goal-trackers* fixated on the *goal,* relative to the cue, more frequently (fixation count, *figure 4.*9iA) , for a longer duration (dwell time, *figure 4.*9iiA), returned to the *goal* more rapidly at trial onset (latency, *figure 4.*9iiiA) and at a higher frequency throughout the trial (run count, *figure 4.*9ivA). The opposite was true of the *sign-trackers.*

i

Fixation count	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
goal	1.43	0.15	0.08	0.07	0.57	0.10

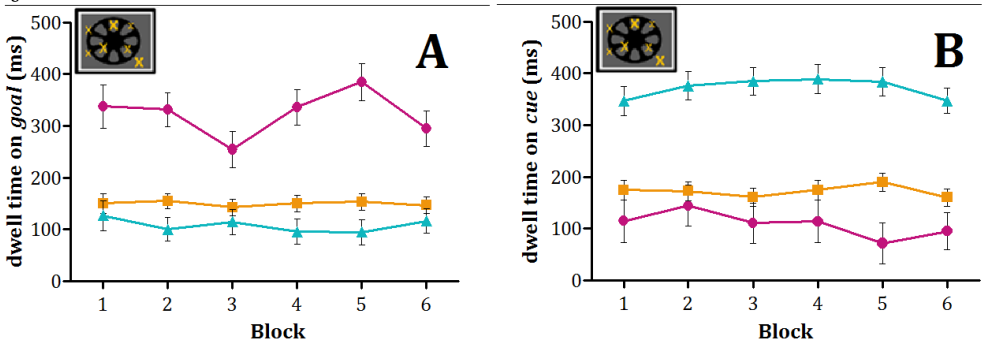
Fixation count	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
cue	0.64	0.17	0.89	0.08	1.70	0.11



ii

Dwell Time	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
goal	323.54	32.88	149.78	13.09	108.25	15.35

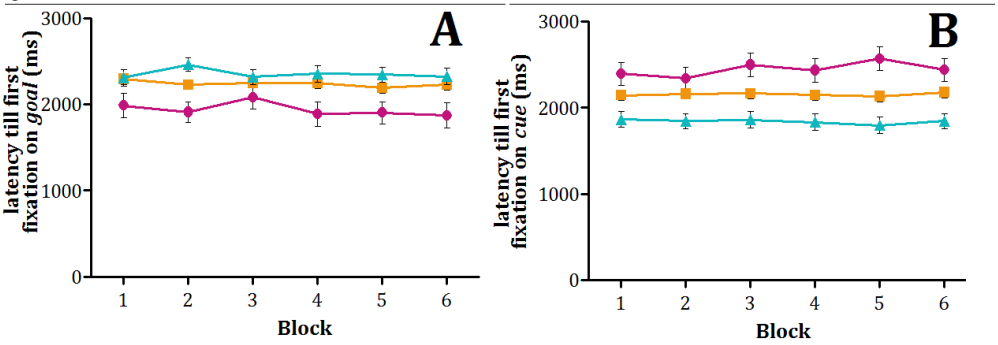
Dwell Time	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
cue	108.51	2.63	172.23	16.31	371.59	16.68



iii

Latency	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
goal	1941.48	112.18	2241.61	50.81	2352.81	76.95

Latency	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
cue	2447.76	116.16	2156.76	116.16	1843.65	79.68



iv

Run count	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
goal	0.86	0.11	0.57	0.05	0.44	0.07

Run count	Goal-Tracker		Intermediate		Sign-Tracker	
	M	*SE*	*M*	*SE*	*M*	*SE*
cue	0.38	0.17	0.63	0.04	0.95	0.07

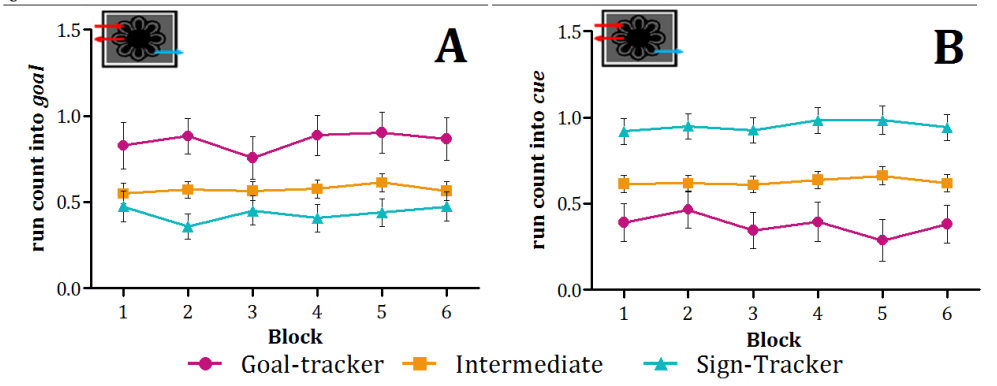


Figure 4.9: shows **(i)** fixation count, **(ii)** dwell time, **(iii)** latency and **(iv)** run count across *block* split by *image, goal* **(A)** and *cue* **(B)**, and *PCG classification* (error bars show ± S.E; note what small tables show)

	Goal-Tracker		Intermediate		Sign-Tracker	
	M	***SE***	***M***	***SE***	***M***	***SE***
Fixation count						
Overall	0.97	0.13	0.79	0.59	1.06	0.89
Goal	1.43	0.15	0.08	0.07	0.57	0.10
Cue	0.64	0.17	0.89	0.08	1.70	0.11
Dwell Time						
Overall	202.80	24.22	151.14	10.97	225.11	16.61
Goal	323.54	32.88	149.78	13.09	108.25	15.35
Cue	108.51	2.63	172.23	16.31	371.59	16.68
Latency						
Goal	1941.48	112.18	2241.61	50.81	2352.81	76.95
Cue	2447.76	116.16	2156.76	116.16	1843.65	79.68
Run Count						
Goal	0.86	0.11	0.57	0.05	0.44	0.07
Cue	0.38	0.17	0.63	0.04	0.95	0.07

Table 4.4: displays the means and ±SE for each *PCG classification* split by *image*

4.4.2.2: the relationship between PCG classifications and awareness:

To ascertain whether *PCG classifications* were based on performance, and not knowledge of Pavlovian contingencies, we examined whether interactions existed between *awareness*, *PCG classifications* and each of the behavioural measures. Two-way ANOVAs on overall fixation count, dwell time, latency and, run count revealed no significant interactions between *awareness* and *PCG classifications* (p *s*$< .106$, see table 2.4 in appendix 2. Table 2.5 in appendix 2 shows non-significant interactions between contingency, awareness and PCG class and table 2.6 in appendix 2 shows non-significant interactions between contingency, awareness, image and PCG class on overall eye-tracking measures).

As the sample sizes of the *PCG classifications* were small, additional analyses were carried out to verify this finding. The results of a Chi-square revealed no relationship between *PCG classification* and *awareness,* $\chi^2(2, N=64) = 0.61$, $p = .737$. Odds ratios, comparing *awareness* classifications

across groups (see *table* 4.5), indicated that sign-trackers were more likely to be aware than goal-trackers but it appears that classification did not rely on awareness status. Collectively, these results support the assertion that the attentional biases demonstrated by the participants were distinct from knowledge of *contingency*.

PCG classification	**Odds ratio:**	**% *Aware* participants**	
	Aware	**Within *PCG class***	**In other *PCG classes***
Sign-tracker	1.14	64.7	61.7
Intermediate	1.07	64.1	60.0
Goal-tracker	0.78	50.0	64.3

Table 4.5: shows odds ratios for being designated *aware* and proportions of *aware* participants across *PCG classifications*

4.4.2.3: relation between PCG classification and evaluative conditioning:

Next pleasantness or anxiety ratings for stimuli (cue10, cue50, cue90 and goal) were examined in order to ascertain whether they differed across PCG classifications; there were no significant differences (*figure 4.*10).

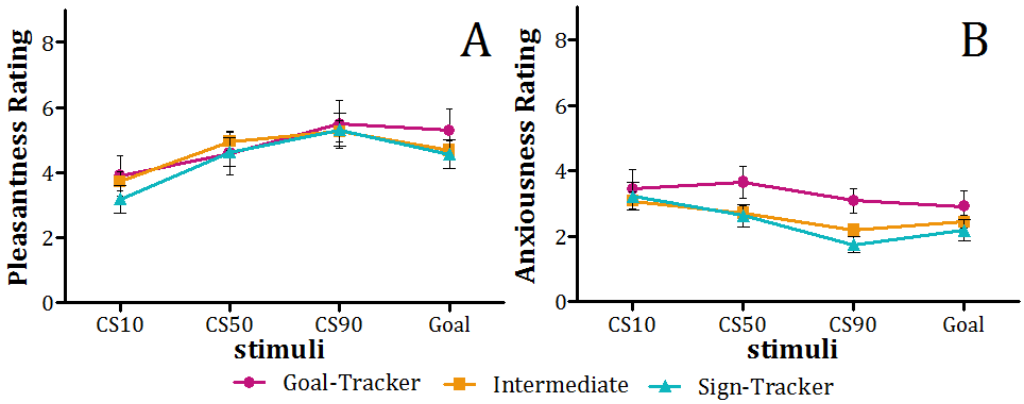


Figure 4.10: shows evaluative conditioning ratings of *stimuli* (cue10, cue50, cue90 and goal) split by *PCG classification*: **(A):** shows pleasantness ratings **(B):** anxiety ratings (error bars show ± S.E)

Analysis was then conducted including awareness; however, revealed no significant differences or interactions (see table 2.9 appendix 2).

	CUE						GOAL					
	CS10		CS50		CS90		goal10		goal50		goal90	
	M	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***
Fixation count												
Goal-Tracker	0.63	0.18	0.66	0.17	0.64	0.17	1.34	0.16	1.44	0.15	1.5	0.16
Intermediate	0.93	0.08	0.98	0.08	0.827	0.08	0.76	0.07	0.79	0.07	0.86	0.07
Sign-Tracker	1.69	0.12	1.72	0.12	1.69	0.11	0.54	0.11	0.57	0.10	0.59	0.11
Dwell Time												
Goal-Tracker	107.28	36.24	114.43	35.28	103.83	31.52	310.77	31.31	333.37	28.06	326.47	30.79
Intermediate	183.23	16.41	176.07	15.94	157.35	14.27	143.58	14.18	143.42	12.71	162.39	13.95
Sign-Tracker	367.48	24.86	385.71	24.143	361.68	21.62	101.35	21.48	106.86	19.25	116.53	21.12
Latency												
Goal-Tracker	2452.78	130.71	2440.73	119.86	2449.78	117.12	1981.72	129.35	1909.04	119.11	1933.67	118.29
Intermediate	2109.96	59.28	2156.09	54.29	2204.29	53.05	2281.44	58.58	2253.82	53.95	2189.38	53.58
Sign-Tracker	1832.2	89.66	1855.28	82.23	1843.54	80.35	2399.68	88.73	2347.32	81.71	2314.44	81.15
Run Count												
Goal-Tracker	0.38	0.10	0.38	0.10	0.38	0.18	0.81	0.12	0.88	0.11	0.87	0.11
Intermediate	0.66	0.05	0.63	0.05	0.59	0.05	0.54	0.05	0.57	0.05	0.62	0.05
Sign-Tracker	0.95	0.07	0.95	0.07	0.96	0.07	0.42	0.08	0.43	0.07	0.46	0.07
Pupil change												
Goal-Tracker	3.13	1.66	2.66	1.62	-0.004	1.64	-0.96	1.92	-0.32	2.31	-1.62	1.94
Intermediate	0.08	0.79	0.05	0.77	0.41	0.78	1.04	0.92	0.27	1.11	0.13	0.93
Sign-Tracker	-2.58	1.14	-1.58	1.11	-2.59	1.12	5.55	1.32	3.70	1.59	5.51	1.33

Table 4.6: shows the fixation count, dwell time, run count, latency and pupil change split by *image, contingency* and *PCG classifications. (Table 2.7 in appendix 2* shows Ms & SEs for three-way interaction awareness, contingency and PCG class, *table 2.8* in appendix 2 shows four way interaction contingency, awareness, PCG class. and image; , *table 2.10* in appendix 2 shows four way interaction contingency, awareness, block and image).

4.4.2.4: The effect of contingency across image between PCG classifications:

Table 4.6 shows that *contingency* did not have the same effect across *images or PCG classifications*. A two (image: cue, goal) by three (contingency: 90, 50, 10) by three (PCG class.: sign-tracker, goal-tracker, intermediate) ANOVA was carried out to assess the effect of image and contingency within PCA classifications; however, there were no significant differences so all analysis is descriptive.

4.4.2.4.1: Comparing the effect of contingency on eye-tracking measures on the Cue across PCA classifications.

Sign- and goal-tracking participants spent the longest duration dwelling on the CS50 (although it should be noted that average dwell time by sign-trackers on the CS50 was over 3 times the duration of that of the goal-trackers), whereas Intermediates spent the longest duration dwelling on the CS10. In terms of fixation count on the cues, there was minimal difference across levels of contingency; however, for all three PCA classifications the highest fixation count was on the C50. There were minimal differences in run count across contingencies for all PCA classifications, though it is worth noting again that fixation count on all cues by sign-trackers was twice that of goal-trackers. For both sign-trackers and intermediates, the fastest latency until first fixation was for the CS10, the opposite of goal-trackers whose longest latency until first fixation was for CS10. Goal-trackers were fastest to fixate on the CS50, which was the opposite of the sign-trackers who were slowest to fixate on the CS50. Intermediates were slowest to fixate on the CS90.

4.4.2.4.2: Comparing the effect of contingency on eye-tracking measures on the Goal across PCA classifications.

Intermediate and sign-tracking participants spent the longest duration dwelling on the goal90, whereas goal-trackers spent the longest duration dwelling on the goal50. All PCA classifications fixated on the goal90 the most and goal10 the least, and again the fixation count by goal-trackers was double that of sign-trackers at all contingencies. There were minimal differences in run count, within PCA classifications, for all contingencies; though run count by goal-trackers into the goal, at all contingencies, was twice that of sign-trackers. Intermediate and sign-trackers were fastest to fixate on the goal90 whereas goal-trackers were fastest to fixate on the goal50.

4.4.2.5: Comparing questionnaire measures across PCG classifications:

This final section of the results aimed to explore differences in the PCG classifications in terms of alcohol consumption, drug use and impulsivity measures.

4.4.2.5.1: AUQ binger classification:

Within the sample, 21 participants were identified as *Non-Bingers (*Binge score of 8 or less), 22 *Bingers* (binge score of 16.5 or more) and 22 *unclassifiable (*see General Methods; Townsend & Duka, 2002*).* All *unclassifiable* participants were excluded from further analysis. Analysis revealed there were no significant differences in *AUQ or binge scores* across *PCG classification* or *awareness (*see *table 4.7*).

There was a significant difference between *BIS classifications* and AUQ score, $F(2, 61) = 6.24$, $p = .003$, partial $\eta^2 = .17$. *AUQ score* was significantly higher in *highly impulsive (n=8)* than the *normal (n=41, p =.045)* and *overly controlled* groups *(n=16, p =.002,* see *table 4.7*).

There was also a significant difference in *binge scores* across *BIS classifications*, $F(2, 61) = 4.61$, $p = .014$, partial $\eta^2 = .13$. Binge score was significantly higher in *highly-impulsive* than *overly-controlled* group ($p = .019$; see *table 4.7*). Finally, *binge score* and *AUQ score* did not correlate with discounting rate, for any reward amount including average.

		AUQ: AUQ score		**AUQ: binge score**	
		M	***SE***	***M***	***SE***
PCG	*Goal-Tracker*	25.56	7.68	16.63	4.88
	Intermediate	23.58	3.48	14.92	2.21
	Sign-Tracker	29.13	5.27	17.92	3.34
BIS	*Goal-Tracker*	46.31	7.53	24.96	4.88
	Intermediate	25.91	3.11	17.30	2.02
	Sign-Tracker	14.56	4.98	8.48	3.23

Table 4.7: shows average AUQ and binge scores across BIS and PCG classifications

4.4.2.5.2: Barratt impulsivity scale (BIS-11) classification:

Forty one participants reported *normal* levels of impulsivity, 8 *highly impulsive* and 16 *overly-controlled.* There were no significant differences in *BIS total score* between *PCG classifications*, $F(2, 61) = 1.49$, $p = .233$. However, a 6x (*BIS subscales*: *attention, cognitive instability, motor, perseverance, self-control* and *cognitive complexity*) 3 (*PCG classifications*: *intermediate, sign-, goal-tracker)* revealed a significant interaction, $F(10, 305) = 2.03$, $p = .030$, partial $\eta^2 = .06$. Further analysis revealed that scores of perseverance were significantly higher in *sign-trackers* than *goal-trackers (p =.035;* see *figure 4.11*)

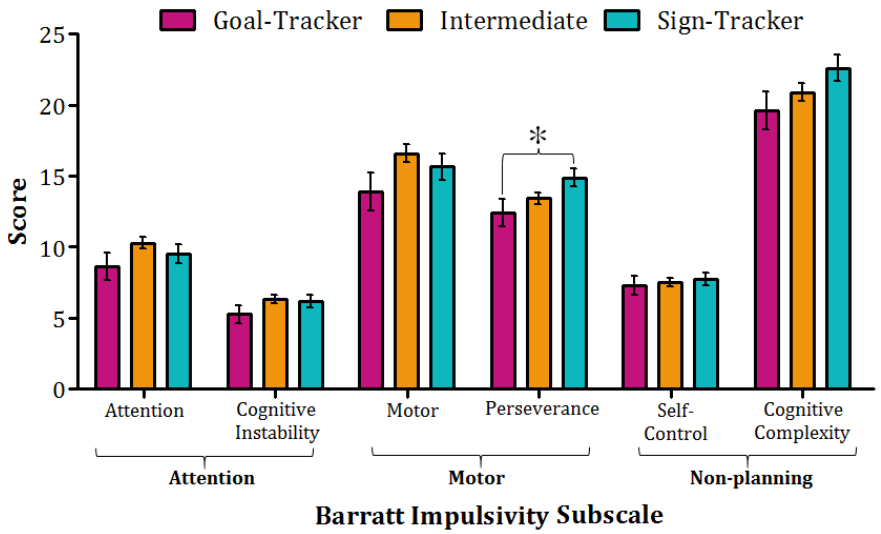


Figure 4.11: shows average score on each of the BIS subscales across *PCG classifications* (error bars show ± *SE,* asterisks denote significant differences)

Lastly, discounting rates were assessed across *BIS classifications (highly impulsive, overly controlled and normal)*, and no significant differences were found between groups and discounting rates did not correlate with *total BIS score.*

4.4.2.5.3: DUQ: Poly Drug Classification:

Twenty six participants reported having never tried THC based products and 35 reported having never tried any of the other illicit substances in the DUQ. There were 9 *single-drug* participants and 29 *poly-drug users*. There were 51 *non-smokers.* Results revealed no significant difference in discounting rate between *poly-drug* and *single drug* participants. P*oly drug* users had a significantly higher AUQ score (*M*=38.18, *SE*=3.87*) th*an *single-drug* users (*M*=14.64, *SE*=2.63, *t (62)* =-5.17, *p*<.001) and a significantly higher binge score (*M*=23.49, *SE*=2.55*)* than *single-drug* users (*M*=9.66, *SE*=1.69, *t (62)* =-4.66, *p*<.001)

4.4.2.5.4: discounting rates:

There was a significant effect of *reward size* on discounting rate; *F* (1.72, 104.84) =28.41, *p* <.001, partial η^2= .32. Analysis of average discounting rate revealed that participants discounted the medium rewards (*M*=0.02, *SE*=0.01) significantly faster than the large rewards (*M*=0.01, *SE*=0.004, *p* =.002). The small rewards (*M*=0.03, *SE*=0.005) were discounted significantly faster than the medium (*p* <.001) and large (*p* <.001) rewards.

The effect of *reward size* on discounting rate was examined across *PCG classifications*; though non-significant *figure* 4.12 shows that *goal-trackers* discounted the large reward more slowly than both the *intermediates* and *sign-trackers*.

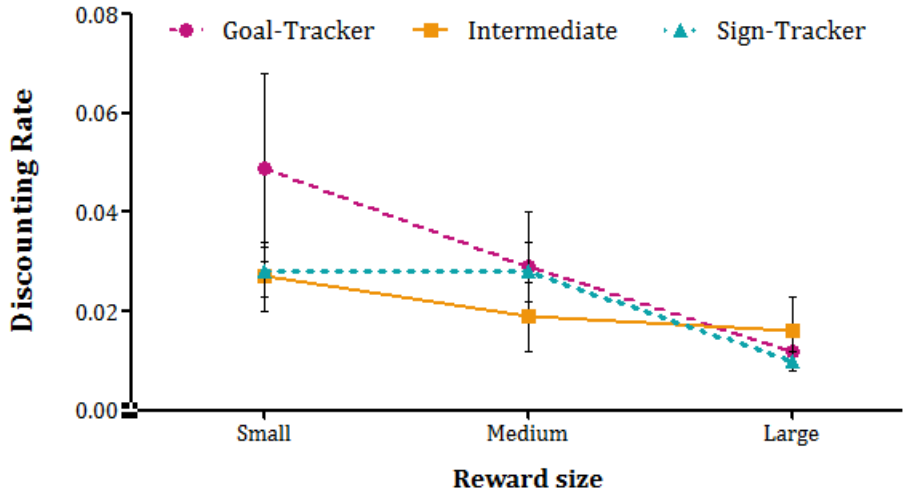


Figure 4.12: shows discounting rate across levels of *reward size* split by *PCG classifications* (error bars show ± *SE)*

As sample sizes of the *PCG classifications* were small, odds ratios were calculated to further examine alcohol/drug-use and impulsivity scores across *PCG classifications* (see *table 4.8*). The odds ratios showed *sign-trackers* were over twice as likely to be binge drinkers than *goal-trackers* were. Contrary to evidence from animal literature, *goal-trackers* were the most likely to be *poly-drug* users and *sign-trackers* least. The likelihood of having "*normal*" levels of impulsivity (according to the *BIS classification)* was very similar across all *PCS classifications* but, in accordance with previous research, *goal-trackers* were twice as like to be "*overly-controlled*" than *sign-trackers*.

	Binge drinker	***Poly-drug user***	***BIS classifications***		
			Highly-Impulsive	**Normal**	**Overly-controlled**
Goal-tracker	0.63	1.24	---	0.93	1.99
Intermediate	1.06	1.09	1.69	1.00	0.77
Sign-Tracker	1.7	0.79	1.12	1.04	0.98

Table 4.8: shows odds ratios for being, and proportions of, participants designated *binge drinkers, poly-drug users* or in the *top 50% of BIS scores* across *PCG classifications*

4.5: Discussion

Through this experiment, the distinct conditioned response groups of intermediates, sign and goal-trackers were identified in humans using eye-tracking measures. While designation of conditioned response groups was done on the basis of dwell time, which is intrinsically linked with the measure fixation count (see figure 4.4), results from the other measures (latency, run count and pupil dilation) support the conditioned response classifications. The results from each of these measures across time also supports the assertion that *PCG classification* represents a consistent bias. Therefore, we can be confident that the *PCG classification* reflects a reliable behavioural response bias within our sample. Importantly, section 1 separated awareness from the behavioural response groups, meaning that, as in non-human animal models, the response topography is down to individual differences rather than a deficit in learning (Meyer et al., 2012). Furthermore, as research into sign- and goal-tracking in humans has been so limited thus far, this result is promising in that the eye-tracking measures used here could provide an equivalent to recent work on sign- and goal-tracking in rats by Olshavsky et al. (2014), wherein behavioural classification was done on the basis of orienting responses.

While section 1 showed that contingency has dissociable effects on the goal and cue, as contingency increased so did bias towards the cue and away from the goal, there was little evidence that reward probability differentially affected conditioned responses in any PCG classification in particular, as suggested by previous research (Davey et al., 1981; Davey & Cleland, 1982; Anselme et al., 2013; Robinson et al., 2015). However, this might be the result of the small number of participants in each PCG classification but, having established a method of identifying different response groups, this is an area for potential future research.

Analysis showed that, despite goal-trackers focussing their attention on the *goal* significantly more than the *cue* and the reverse in sign-trackers, there were no significant differences in ratings of pleasantness of the goal and cue across *PCG classifications.* This result suggests that, while the stimuli might be more "attention grabbing", it is not necessarily *liked* more than the other cue, which is an interesting dissociation. This suggests that across PCG c*lassifications* that predicted and remembered utility were equal; however, goal-trackers and sign-trackers showed behavioural biases towards the goal and cue respectively. Put in terms of utility, this can be explained by sign-trackers' decision utility exceeding their predicted and remembered utility of the reward.

However, what is not clear is when this increase would occur: on presentation of the cue and goal together or on presentation of the feedback message.

The measure percentage change in pupil dilation showed a reliable dilation when the goal was presented, whereas across the majority of blocks participants' pupils constricted on presentation of the cue. There are several potential explanations for this. The first explanation is that the goal might produce more emotion as it is the site of reward delivery leading to increased arousal and dilation of the pupil on presentation. Alternatively, the reward message appears across the goal and the participants' pupils may have increased with the, comparatively, higher cognitive load.

Results from the questionnaire analysis provided a single significant indicator for sign- and goal-tracking, the *BIS-11* subscale, *perseverance.* The Kirby et al. (1999) delay discounting questionnaire revealed that *goal-trackers* discounted their rewards more slowly than both *sign-trackers* and *intermediates;* which, though non-significant is much in keeping with earlier findings by Tomie, Aguado, Pohorecky, & Benjamin, (1998) and suggests a potential link between impulsive choice and conditioned response topography.

A confound of this experiment is that while each of the cues were presented 60 times over the course of the protocol, the same goal image was presented 180 times. Therefore, the next experiment aims to elucidate whether the bias towards the cue or goal, observed in experiment 4.1, was the result of repeated exposure to the goal image. Previous research has demonstrated that mere repeated exposure can alter liking (Zajonc, 1968; Zajonc, Markus, & Wilson, 1974). Therefore, we cannot be certain that any bias demonstrated towards the goal is not the result of familiarity. Further to this, the overall contingency of reward receipt for the cue and goal images across the 180 trials in experiment 4.1 was 50%, however, as the goal was presented across all trials, whereas each cue was only presented for a third. Therefore, 100% of the reward messages appear with a single goal image and, this might influence the participants' perception of the probability of reward receipt on its appearance. By presenting a distinct cue and goal for each reward contingency, the next experiment aims to match the probability of reward receipt across goals and cues and to determine whether observed bias towards the goal or cue is the result of repeated exposure.

4.6: Experiment 4.2:

The aims of this experiment were to assess whether goal-tracking observed in experiment 4.1 was bias produced by exposure to the *goal* in excess of the *cue* and to match the contingency of reward receipt across *images*.

4.7: Method

4.7.1: Participants, materials and procedures:

Thirty-two healthy participants were recruited as before. Average BMI (M=22.03, SE= 0.58), age (18 -24 years, M= 19.21, SE=0.29) did not differ between experimental conditions or sexes.

The materials used were identical to experiment 4.1 but the procedure was adjusted to control for familiarity of the cue and goal stimuli by presenting a unique goal image with each CS contingency. Thus, on each trial participants were presented with a *goal* and *cue* image, associated with reward delivery on either 50% *(CS50* and Goal50) or on 0% (CS0 and Goal0) of trials. Each *block* consisted 20 trials of each CS+goal contingency (40 trials total) for a total of three blocks (120 trials in total).

4.7.2: Data Analysis: Data were analysed as before.

4.7.2.1: awareness:

Participants were classified as aware if their rating of the 50% images (goal and cue) was 5 times higher than the rating of the 0% images. There were 15 *aware* and *17 unaware* participants.

4.7.2.2: Pavlovian conditioned gaze:

PCA index was calculated, a table of values is available in appendix 2 (table 2.11). For the sake of consistency, the same methodology for assigning participants to a PCG classification were used here as in experiment 4.1. According to this criteria, 11 were goal-trackers, 18 were intermediates and 3 were sign-trackers. A table of behavioural classifications (binger, poly, BIS) across PCG classifications is in appendix 2 (Table 2.12)

4.7.2.3: Corrections and Statistics:

The only variable to deviate significantly, and repeatedly from normal, was the percentage change in pupil dilation; log, square root and reciprocal transformations were applied. Further analysis revealed that none corrected the deviations, so the original data were used; interpretation must be done with caution.

4.8: Results:

4.8.1: Section 1: Establishing measures:

4.8.1.1: The effect of contingency on eye-tracking measures.

Fixation count, dwell time, run count, latency and pupil change data were assessed for main effects of *contingency* (50 & 0); there were no significant effects for fixation count, run count or percentage change in pupil dilation (see table 2.13 in appendix 2). Differences in dwell times on the CS50 (M=239.58, SE= 15.87) versus CS0 (M=226.78, SE= 15.68) approaching significance, t (31) = 2.03, p =.051. Likewise, participants were significantly faster to fixate on the 50% images (M=837.38, SE= 47.47) than the 0% (M=876.03, SE= 268.98, t (31) = -2.55, p =.016).

4.8.1.2: The effect of contingency across images (goals, cues):

There were no significant main effects of, or interactions between, the variables *contingency* and *image* for any of the behavioural measures.

4.8.1.3: Awareness:

Initially, data were examined in order to ensure that those classified as aware and unaware had significantly different expectancy ratings. There was no overall effect of awareness. There was a significant main effect of image, (F (1, 30) =44.54, p<.001, partial η^2= .68); participants rated the goals (M=34.90, SE=1.96) as significantly more likely to be followed by reward than the cues (M=23.87, SE=2.34). There was also a significant effect of contingency, F (1, 30) =130.78, p<.001, partial η^2= .81, the 50% images (M=44.45, SE=2.57) were rated as significantly more likely to be followed by reward than the 0% images (M=14.32, SE=2.19).
There was a significant interaction between *image* and *awareness*, F (1, 30) =6.83, p=.014, partial η^2= .19. A*ware* participants rated the *cue* (M=26.34, SE=3.09) as more likely to be followed by reward than unaware participants (M=21.39, SE=3.51). The *unaware* rated the *goal* (M=36.75, SE=2.94) as more likely to be followed by reward than the aware participants (M=33.06, SE=2.68).

Results showed a significant interaction between *contingency* and *awareness*, F (1, 30) =50.34, p<.001 partial η^2= .63; A*ware* participants rated the *50%* (M=54.11, SE=3.40) as more likely to be followed by reward than the *unaware* participants (M=34.79, SE=3.86). Whereas the *unaware* participants rated the *0%* (M=23.36, SE=3.29) as more likely to be followed by reward than *aware* counterparts (M=5.29, SE=2.98).

A significant interaction effect was observed between *image* and *contingency* F (1, 30) =10.38, p=.003, partial η^2= .26. The ratings of the *CS0 (M*=14.11, *SE*=2.55) and *goal0 (M=14.53, SE*=2.73) did not differ considerably, whereas the *goal50 (M*=55.27, *SE*=3.11) was rated as more likely to be followed by reward than the *CS50 (M*=33.62, *SE*=3.58).

There was no significant interaction between the variables *awareness, image* and *contingency*. *Figure 4.*13 shows the differences in ratings across stimuli by participants, the distinction comes from a tendency by the *unaware* participants to overestimate the predictive value of the 0% stimuli.

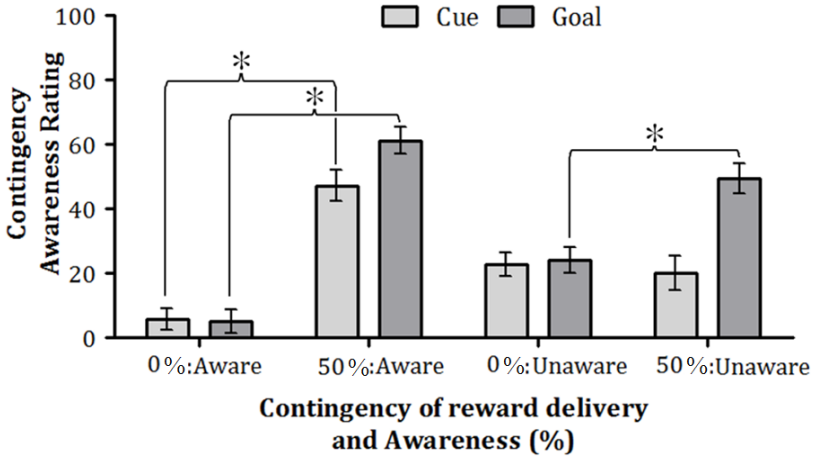


Figure 4.13: shows the *contingency* ratings of stimuli split by *awareness* classification (error bars show ± S.E) Asterisks denote significant differences.

4.8.1.4: The effect of awareness on eye-tracking measures:

There no significant effects of awareness on any of the eye-tracking measures. Table 4.9 shows that aware participants had longer dwell times and higher fixation and run counts than unaware counterparts. Unaware participants were faster to fixate on an image at the onset of a trial than the aware participants. However, the differences were not significant.

	Dwell time		Fixation count		Run Count		Latency (ms)	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Aware	239.72	19.72	0.86	0.32	0.63	0.23	834.33	59.85
Unaware	199.72	19.48	0.82	0.29	0.58	0.19	792.88	69.21

Table 4.9: shows the average latency till first fixation, fixation and run count on *images* (*goal, cue)* split by *awareness* classification.

4.8.1.5: The effect of awareness on evaluative conditioning:

4.8.1.5.1: Pleasantness:

Analysis revealed no significant main effects of contingency (0, 50) or image (goal or cue) or significant interactions on ratings of pleasantness.

4.8.1.5.2: Anxiety:

Unrelated to *awareness,* there was a significant effect of *image* on ratings of *anxiety*, F (1, 30) =9.70, p=.0014 partial η^2= .24. The *goal* induced significantly more anxiety (M= 2.77, SE= 0.27) than the *cue* (M= 2.39, SE= 0.22).

There was a significant interaction effect between *contingency* and *image*, F (1, 30) =10.66, p=.001, partial η^2= .26. When the *contingency* was 0, participants reported feeling more anxious when presented with the *cue* (M =2.41, SE =0.27) than the *goal* (M =2.23, SE =0.29). At 50% the *goal* (M =3.32, SE =0.36) produced more anxiety than the *cue* (M =2.36, SE =0.28).

4.8.2: Section 2: PCG classifications

According to the PCG, there were 11 goal-trackers, 18 intermediates and 3 sign-trackers. Initial analysis revealed there was no significant differences in dwell times, fixation count, run count or latency to respond across PCG classifications. Following this, eye-tracking measures were assessed across *Pavlovian conditioned gaze classification, block* and *image (*means and SE available in *table 4.10*).

4.8.2.1: differences in eye-tracking measures between PCG classifications across blocks and images

There was a significant main effect of block on fixation count only, F (2, 58) =3.38, p=.041, partial η^2=.104. There were significantly more fixations during block 1 (M=0.99, SE= 0.08) than block 3 (M=0.89, SE= 0.08, p=.050).

There was a significant interaction between i*mage* and *PCG classification* for fixation count, F *(2, 29)* =19.31, p< .001, partial η^2= .57(*figure 4.*14i), dwell time F *(2, 29)* =39.53, p< .001, partial η^2= .73 (*figure 4.*14ii), run count, F *(2, 29)* =22.17, p< .001, partial η^2= .61 (*figure 4.*14iii) and latency , F *(2, 29)* =17.15, p< .001, partial η^2= .54 (*figure 4.*14iv).

Goal-Trackers completed significantly more fixations t (10) =5.34, p< .001 (*figure 4.*14ia), dwelt for significantly longer t (10) =5.97, p<.001 (*figure 4.*14iia), made significantly more runs into, t

(10) =-6.76, $p < .001$ (*figure 4.*14iiia), and had a significantly faster latency to fixate on, t (10) =4.23 $p = .002$ (*figure 4.*14iva), the *goal* than on the *cue*.

Conversely, *sign-Trackers* completed more fixations (*figure 4.*14ib), dwelt on (*figure 4.*14iib), made more runs into (*figure 4.*14iiib) and had a faster latency to fixate on (*figure 4.*14ivb) the cue over the goal, but these differences failed to reach significance.

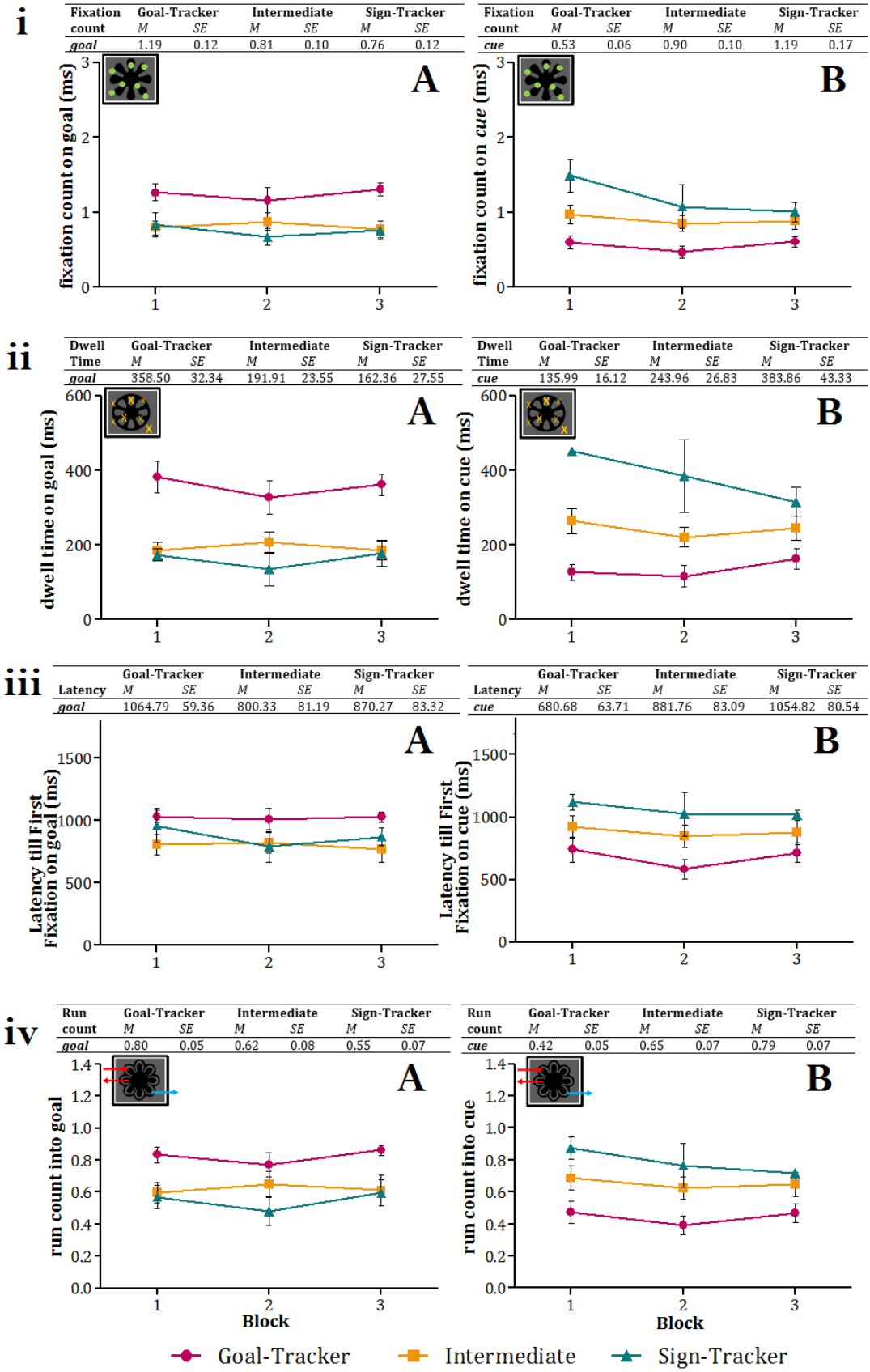


Figure 4.14: shows **(i)** fixation count, **(ii)** dwell time, **(iii)** latency and **(iv)** run count across *block* split by *image, goal* **(A)** and *cue* **(B),** and *PCG classification* (error bars show ± S.E; note what small tables show)

	Goal-Tracker		Intermediate		Sign-Tracker	
	M	***SE***	***M***	***SE***	***M***	***SE***
Fixation count						
Goal	1.25***	0.12	0.76	0.23	0.82	0.09
Cue	0.56	0.11	1.19	0.2	0.9	0.08
Dwell Time						
Goal	357.29***	30.12	162.68	57.67	192.98	23.55
Cue	135.99	28.56	383.86**	54.68	243.95	22.32
Latency						
Goal	1026.08***	84.88	800.16	66.29	873.62	162.38
Cue	680.68	90.25	881.75	70.55	1054.82	172.801
Run Count						
Goal	0.82**	0.08	0.55	0.15	0.62	0.06
Cue	0.45	0.07	0.79	0.13	0.65	0.05
% pupil dilation						
Goal	28.79	7.2	1.95	5.26	-0.22	12.89
Cue	-21.3	6.73	8.05	5.63	11.24	13.79

Table 4.10: displays the means and SE for each *Pavlovian conditioned gaze classification* split by *image* *=p <.05, **= p <.01, ***= p <.001)

4.8.2.2: the relationship between PCG classification and awareness:

Analysis on overall *goal* and *cue* fixation count, dwell time, latency and, run count no significant interactions between *awareness* and *Pavlovian conditioned gaze classifications* (p *s*< .623, see table 2.14 in the appendix 2. Table 2.15 in appendix 2 shows non-significant interactions between contingency, awareness and PCG class and table 2.16 in appendix 2 shows non-significant interactions between contingency, awareness, image and PCG class on overall eye-tracking measures). As in experiment 4.1, the sample sizes across groups were small so additional analyses were carried out to confirm this assertion. The results of a Chi-square revealed no relationship between *PCG classification* and *awareness,* χ^2 (2, *N*=32) =.524, p =.770. This result supports the assertion that the attentional biases demonstrated by the participants were distinct from knowledge of *contingency*. However, odds ratios were calculated, comparing *awareness* classifications across groups (see *table* 4.11), these suggest that (contrary to experiment 4.1) goal-trackers were more likely to be aware than sign-trackers.

PCG classification	Odds ratio: *Aware*	% *Aware* participants	
		Within *PCG class*	In other *PCG classes*
Sign-tracker	0.06	5.60	94.4
Intermediate	0.80	44.4	50.0
Goal-tracker	1.6	54.5	42.9

Table 4.11: shows odds ratios for being designated *aware* and proportions of *aware* participants across *PCG classifications*

4.8.2.3: relation between PCG classification and evaluative conditioning

In terms of pleasantness, there were no significant differences in the ratings across *image (goal/cue), contingency (0/50)* and *Pavlovian conditioned gaze classifications.* Analysis was then conducted including awareness; however, revealed no significant differences or interactions (see table 2.16 in appendix 2). In terms of anxiety ratings, there was a significant interaction between the variables image and contingency, F (1, 2) =6.48, p=.017, partial η^2=.18. Ratings of the cue at 0 (*M: 2.12*, *SE:* 0.34) and 50% (*M:* 2.15, *SE:* 0.33) did not differ significantly. However, anxiety ratings of the goal at 0% (*M:* 3.11, *SE:* 0.46) were significantly higher than at 50% (*M:* 1.94, *SE:* 0.35, p=.004). Analysis was then conducted including awareness; however, revealed no significant differences or interactions (table 2.16 in appendix 2).

4.8.2.4: relation between PCG classification and contingency:

The data was then assessed to determine whether fixation count, dwell time, run count, latency and pupil dilation change were significantly different across contingencies (0-50%) between *PCG classifications.* The only significant effect was in pupil change for the *goal-trackers*: *goal-tracker's* pupils increased significantly in response to the CS50 (*M:* 43.68%, *SE:* 13.97) than the CS0 trials (*M:* 2.83%, *SE:* 3.11, t (10) =2.67, p =.023.

4.8.2.5: the effect of contingency across Image between PCG classifications:

As before, the effect of *contingency* was then assessed across *images* between *PCG classifications.* The only significant three way interaction was for change in pupil dilation, F (2, 2) =4.68, p =.017, partial η^2=.24. The difference was in the *goal-trackers* whose pupils were significantly larger when focussing on the goal than the cue at 0% (t (10) =3.45, p =.006) and 50% contingency (t (10) =-2.86, p =.017). Furthermore their pupils' reduced significantly more to the cue at 50% (*M*= -43.62, *SE*= 6.94) than at 0% (*M*= -18.88, *SE*= 5.12, *t (10)* =4.88, p =.001(see *figure 4.*15).

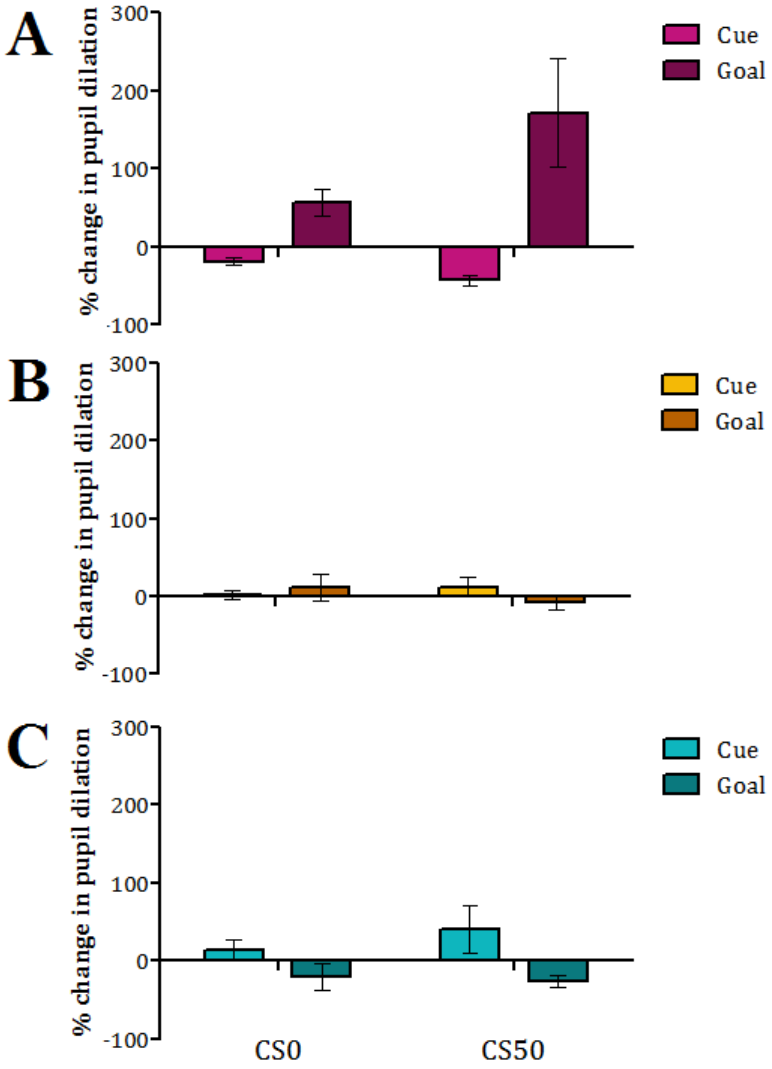


Figure 4.15: shows the average percentage change in pupil dilation in response to CS0 and CS50 *goal* and *cue,* split by *Pavlovian conditioned gaze classification. A) Goal-trackers B) intermediates C) sign-trackers* (error bars show ± S.E)

		CUE				GOAL			
		CS0		CS50		Goal0		Goal50	
		M	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***
Fixation Count	*Goal-Tracker*	0.63*	0.05	0.48	0.05	1.16	0.1	1.32	0.16
	Intermediate	0.91	0.11	0.89	0.11	0.81	0.1	0.82	0.12
	Sign-Tracker	1.2	0.17	1.18	0.18	0.79	0.19	0.73	0.1
Dwell Time	*Goal-Tracker*	151.19*	15.66	120.8	17.97	324.9	36.62	389.53	35.37
	Intermediate	239.98	29.17	248.04	30.8	189.61	28.09	195.74	26.8
	Sign-Tracker	361.71	57.94	406.02	44.24	153.71	40.01	172.46	23.19
Latency	*Goal-Tracker*	764.69*	67.01	596.66	77.33	976.6	58.19	1075.23	51.64
	Intermediate	892.37	89.72	871.31	87.82	824.93	86.26	775.37	90.13
	Sign-Tracker	1084.31	134.74	1025.33	30.93	913.47	109.82	836.65	87.78
Run Count	*Goal-Tracker*	0.50*	0.04	0.39	0.05	0.8	0.05	0.84	0.04
	Intermediate	0.66	0.07	0.64	0.07	0.63	0.08	0.61	0.08
	Sign-Tracker	0.78	0.09	0.79	0.04	0.57	0.1	0.53	0.05
% Pupil Change	*Goal-Tracker*	-18.88	5.12	-43.62	6.94	57.11	16.95	171.47	69.33
	Intermediate	2.17	6	12.6	11.98	11.46	17.89	-7.85	8.85
	Sign-Tracker	14.36	12.27	40.67	30.31	-20.14	17.41	-25.79	7.99

Table 4.12: shows fixation count, dwell time, run count, latency and % pupil dilation across 0 and 50% reward contingencies split by image and PCG classifications. Asterisks denote significant differences, *=p<.05 *(Table 2.17 in appendix 2* shows Ms & SEs for three-way interaction awareness, contingency and PCG class, *table 2.18 in appendix 2* shows four way interaction contingency, awareness, PCG class. and image; *table 2.19 in appendix 2* shows three way interaction contingency, awareness, block and image).

4.8.2.5.1: Comparing the effect of contingency on eye-tracking measures on the Cue across PCA classifications.

Irrespective of PCA classification, participants completed more fixations and had a shorter latency to fixate on the CS50 than the CS0 (see *table 4.*12). Run counts into both CS0 and CS50 were very similar across all PCA classifications, with a slight bias towards the CS0 in the sign and goal-tracker classifications. Goal-trackers spent longer dwelling on the CS0 than the CS50, whereas the reverse is true in both intermediate and sign-tracking participants. For sign-trackers and intermediates the differences between CS0 and CS50 were non-significant but goal-trackers fixated (t (10) =3.10, p=.011), dwelt (t (10) =3.14, p=.011) and returned to (run count, t (10) =2.69, p=.023) the CS0 significantly more than the CS50 (see *table 4.*12).

4.8.2.5.2: Comparing the effect of contingency on eye-tracking measures on the Goal across PCA classifications.

All participant dwelt on the goal50 for longer than the goal0. Goal-trackers were faster to fixate on the goal0 than goal50 but completed more runs into the goal50 than the goal0. Conversely, intermediates and sign-trackers had a shorter latency to fixate on goal50 than the goal, but completed more runs into the goal0 than goal50. Both goal-trackers and intermediates completed more fixations on the goal50 than the goal0 whereas sign-trackers did the reverse (see *table 4.*12).

4.8.2.6: Comparing questionnaire measures across PCG classifications:

This final section of the results aimed to explore differences in the PCG classifications in terms of alcohol consumption, drug use and impulsivity measures

4.8.2.6.1: binger classification:

Ten participants were identified as *Non-Bingers (*Binge score of 12 or less), 11 *Bingers* (binge score of 28 or more) and 11 *unclassifiable. Binge* ranged between 0-77. *Unclassifiable* participants were excluded for grouped analysis, but included for correlations.

Analysis revealed no significant difference in AUQ or binge score across *PCG classifications*. However, there was a significant difference in drinking behaviour across *BIS classifications;* there was a significant difference in AUQ score between *BIS classifications*, F (2, 29) = 7.26, p =.003, partial η^2= .33. AUQ score was significantly higher in *highly-impulsive* group (n=5) than the *normal* group (n=23, p =.007) and *overly-controlled* group (n=4, p =.005). In addition, binge score differed significantly across *BIS classifications*, F (2, 29) = 5.89, p =.007, partial η^2= .29; *highly-impulsive* individuals reported a significantly higher binge score than *overly controlled* (p =.009) and

normal (p =.026) participants (see *table 4.*13). There were no correlations between binge or AUQ score and discounting rate.

		AUQ: AUQ score		AUQ: binge score	
		M	***SE***	***M***	***SE***
PCG	*Goal-Tracker*	30.93	12.14	17.84	5.41
	Intermediate	56.5	9.49	26.82	4.23
	Sign-Tracker	19.33	23.25	17.4	10.37
BIS	*Goal-Tracker*				
	Intermediate	95.8	15.68	42.8	7
	Sign-Tracker	38.36	7.31	20.99	3.26

Table 4.13: shows average AUQ and binge scores across *BIS* and *PCG classifications*

4.8.2.6.2: Barratt impulsivity scale (BIS) classification (Stanford et al., 2009):

Twenty three participants reported *normal* levels of impulsivity, 5 reported being *highly impulsive* and 4 reported being *overly-controlled. Barratt Impulsivity score* ranged between 46 and 9. There were no significant differences in overall *BIS* scores between *PCG classifications*. There were no differences in discounting rates across *BIS classifications.*

Analysis was then carried out on the 6 *BIS subscales* (*attention, cognitive instability, motor, perseverance, self-control* and *cognitive complexity*); this revealed a significant difference, across *PCG classifications,* in *cognitive-instability, F* (2, 29) =4.11, p =.027, partial η^2= .22 and *self-control, F* (2, 29) =3.99, p =.029, partial η^2= .22. *Intermediates* reported significantly higher scores in *cognitive instability* (p=.029) and *self-control* (p=.029) than *goal-trackers.*

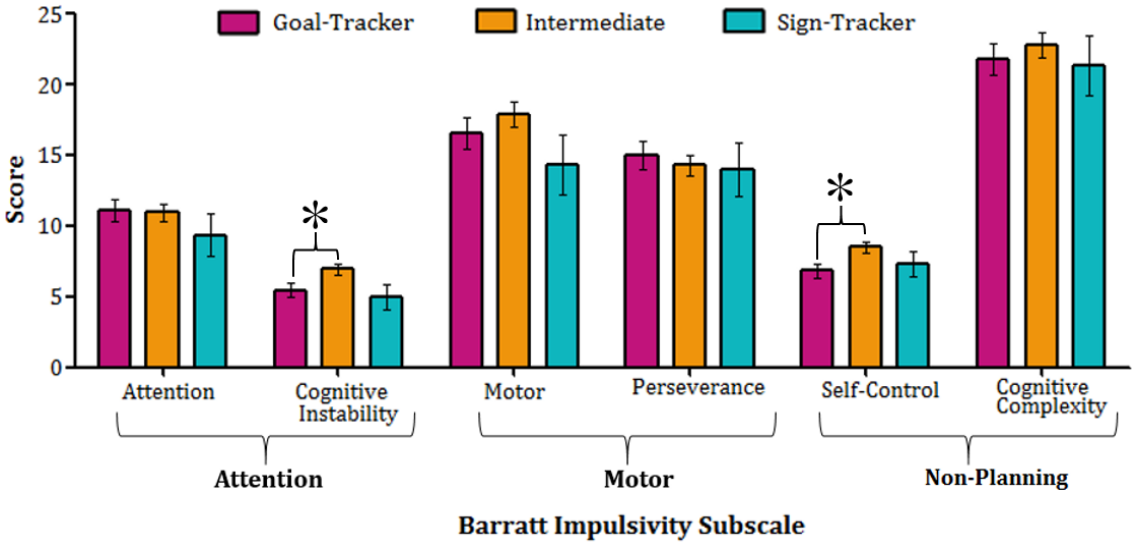


Figure 4.16: shows average score on each of the *BIS subscales* across *PCG classifications* (error bars show ± *SE,* asterisks denote significant differences)

4.8.2.6.3: DUQ: Poly Drug Classification:

Thirteen participants reported having never tried THC based products and 21 reported having never tried any of the other illicit substances in the DUQ. There were 21 *single-drug* participants and 11 *poly-drug users*. There were 26 *non-smokers.* Results revealed no significant difference in discounting rate between *poly-drug* and *single drug* participants. There were no significant differences between *poly drug* and *single-drug* participants in AUQ and Binge score.

4.8.2.6.4: Discounting rates:

There was a significant effect of reward size on discounting rate; F (1.51, 43.68) =10.88, p =.001, partial η^2= .27 (see *figure 4.*17). Analysis of average discounting rate revealed that participants discounted the medium rewards (M=0.02, SE=0.01) significantly faster than the large rewards (M=0.03, SE=0.01, p =.005). The small rewards (M=0.01, SE=0.01) were discounted significantly faster than the medium (p =.005) and large (p =.003) rewards. Though non-significant, figure 4.17 shows that sign-trackers discounted large rewards more slowly than goal-trackers or intermediates.

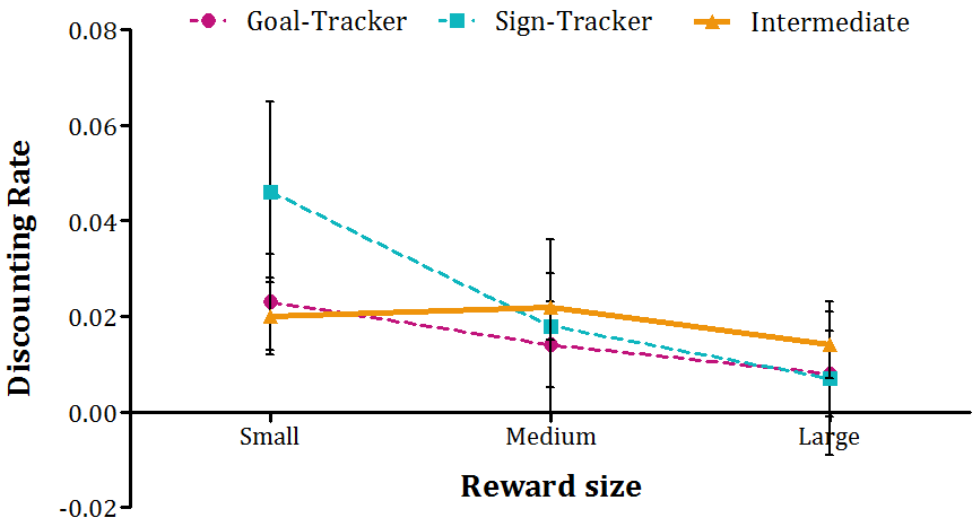


Figure 4.17: shows average discounting rate split by Pavlovian conditioned gaze classification (error bars show ±SE)

Finally, as sample sizes of the *PCG classifications* are small, odds ratios were calculated in order to examine alcohol/drug-use and impulsivity scores across *PCG classifications* (see *table 4.*14). Odds ratios revealed that intermediates were over 5 times more likely to be binge drinkers than other PCG classifications.

			BIS classifications		
	Binge drinker	***Poly-drug user***	**Highly-Impulsive**	**Normal**	**Overly-controlled**
Goal-tracker	0.56	1.43	---	1.75	---
Intermediate	5.6	1.59	0.72	0.18	2.6
Sign-Tracker	0.90	---	---	0.76	4.3

Table 4.14: shows odds ratios for being, and proportions of, participants designated *binge drinkers, poly-drug users* or *BIS classifications* across *PCG classifications*. Where --- appears, this indicates that there were no instance of this group within the *PCG classification*.

4.9: Discussion

PCG classifications were again identified and were shown to be dissociable across multiple eye-tracking measures. Importantly, there was no interaction between PCG classification, image (cue, goal) and contingency (0, 50%), which means that the classification of response groups is not based on the higher reward contingency but reflects a bias in attention even when the chance of reward receipt is zero. In addition to this, the appearance of all images was controlled such that participants saw them an equal number of times, however there was no image by contingency interaction for any of the images which means that the participants were demonstrating the same bias towards the images at both levels of reward probability. This means that the sign- and goal-tracking behaviour observed in experiment 4.1 is not the result of over exposure to the goal or disparity in reward associability.

There was no awareness by PCG interaction, which suggests that the observed behavioural bias is not the result of a knowledge of reward contingency. Although it is interesting to note, however, that in this experiment unaware participants were, at least partially, aware of the goal50 reward contingency; though their rating of this image was significantly less than aware counterparts.

In terms of evaluative conditioning, pleasantness ratings of the goal and cue across contingencies did not differ and they did not differ across PCG classifications. This supports the result of experiment 4.1 that while transient increase in decision utility might lead to sign-trackers directing more of their attention to the cue than the goal, the cue is not necessarily *liked* more

than the goal. Contrary to our hypothesis, participants rated the *cue* as more anxiety inducing at 0% than the *goal* and the reverse at 50%. This provides additional support for one of the conclusions of experiment 4.1 which was that *contingency* effects the *cue* and *goal* differentially. One potential explanation for this is that the feedback message appeared on the goal image; for the goal0 image the predicted utility was equal to the experienced utility throughout, zero. But the expected utility of the goal50 image was 50%, which means that the experienced utility was unequal to the predicted/remembered utility for half the trials and this may have produced the anxiety observed.

Unlike experiment 4.1, there was no consistent difference in pupil dilation across blocks in response to the *goal* and *cue* images. There was however, a significant difference in pupil dilation across PCG classifications and contingencies. Goal-trackers' pupils dilated in response to both goal images and sign-trackers' pupils in response to both cue images, suggesting that the difference might be due to the valance associated with the respective images for each PCG classification (Partala & Surakka, 2003; Lang & Bradley, 2010). This assertion is supported by the fact that goal-trackers' pupils dilated significantly more in response to the goal50 than the goal0. However, an alternative hypothesis is that pupil dilation while emotion may play a limited role in pupil dilation in this experiment, as observed in the sign-trackers, the significant increase in pupil size in response to the goal50 is due to the reward message that appeared across it but not the goal0. If, as proposed in experiment 4.1, the pupil dilation is the result of increased cognitive effort (Hyönä, Tommola & Alaja, 1994; Kahnemann, 2011) then such an account can also explain why the block effect observed in experiment 4.1 was not replicated in experiment 4.2.

Moore & Stickney (1982) made the argument that goal-tracking occurs within a restricted space and dependent on environmental stimuli. Evidence from Morrow, Maren & Robinson (2011) shows that *sign* and *goal-trackers* are differentially effected by environmental cues; *goal-trackers* are more reliant on context than *sign-trackers.* Having established that the behavioural biases observed in experiment 4.1 are not the result of methodology, the next experiment aims to explore further the effect reward contingency on conditioned response topography using cue location as an additional variable. By presenting the cue images in three distinct locations on screen, the next experiment aims to render the cues and their associated contingencies more salient (Griffiths & Mitchell, 2008; Le Pelley & McLaren, 2003).

4.10: Experiment 4.3

4.11: Method:

4.11.1: Participants:

Twenty nine healthy participants (16 female; *M*=20.88, *SE*=0.15; 13 Male; *M*=23.84, *SE*=), ranging years old (*M*=23.85, *SE*=1.83). Neither age nor average BMI (*M*=24.04, SE=0.74) differed significantly across counterbalancing conditions or sex.

4.11.2: Materials:

As used previously in experiment 4.1 and 2

4.11.3: Procedure:

The procedure for this experiment was as in experiment 4.1 apart from each contingency had a designated, reliable position throughout the session. Irrespective of counterbalancing, *cue* images appeared in the top row of rectangles (*Figure 4.*18b) and the *goal* in the bottom. The 50% images always appeared in the middle, while positions of the 10% and 90% images were counterbalanced across participants. As repeated exposure to the goal image was shown to have no effect on goal-tracking in experiment 4.2, the *goal* image was the same across all contingencies. As *goal* and *cue* images always appeared in pairs, the location the *goal* varied to correspond with the location of the *cue* presented during each trial.

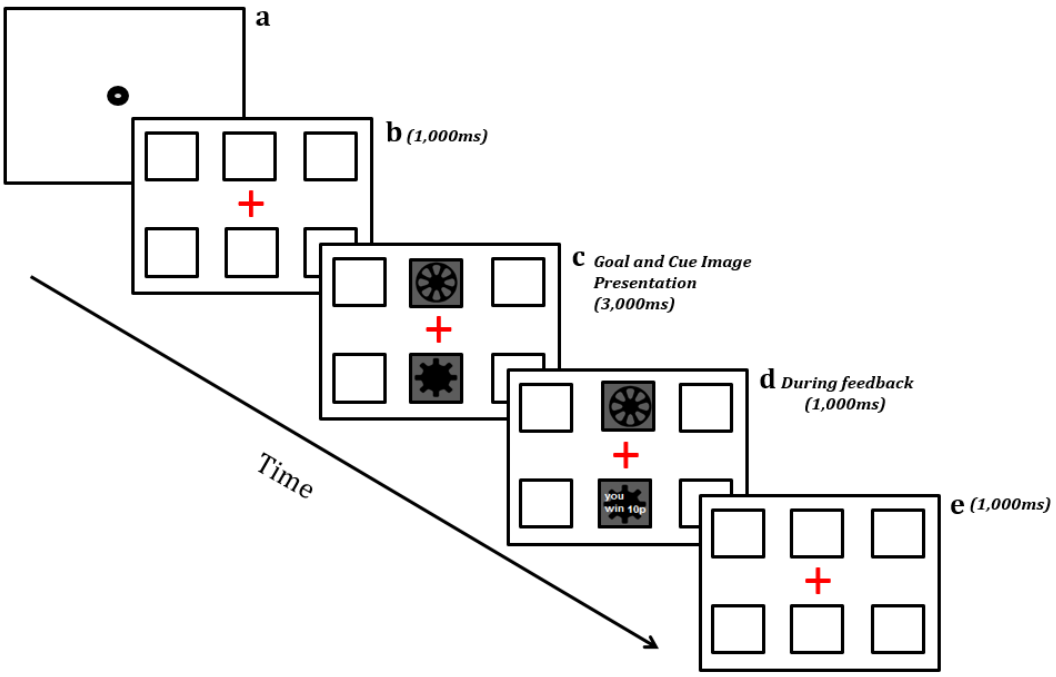


Figure 4.18: shows a reinforced trial sequence between drift corrects for experiment 4.3. Location of 10 and 90% counterbalanced across participants, 50% always appeared centrally.

4.11.4: Data Analysis:

The outcome measures used were the same as described experiment 4.1.

4.11.4.1: awareness:

Awareness was calculated as in experiment 4.1: 15 participants were classified as aware and 14 were classified as unware.

4.11.4.2: Pavlovian conditioned gaze:

PCA index was calculated, a table of values is available in appendix 2 (table 2.20). For the sake of consistency, the same methodology for assigning participants to a PCG classification were used here as in experiment 4.1. On this basis, 6 participants were classified as goal-trackers, 18 were intermediates and 5 were sign-trackers. A table of behavioural classifications (binger, poly, BIS) across PCG classifications is in appendix 2 (Table 2.21).

4.11.4.3: Corrections and Statistics*:*

The variables *Dwell Time, Fixation Count, Run Count,* and, *Percentage change in pupil dilation* were assessed for the assumption of normality. There were significant deviations from normality for *dwell time*; however, transformations failed to correct so data was left untransformed.

4.12: Results:

4.12.1: Section 1: establishing measures

4.12.1.1: The effect of contingency on eye-tracking measures:

There was a significant effect of *contingency* on *dwell time, F* (1.69, 47.32) = 6.23, p =.006 partial η^2= .18; the means revealed that participants dwelt for the longest time on the 90% (*M*= 1024.69, *SE*=270.40*),* followed by 10% (*M*= 1006.27, *SE*=275.81*)* lastly the 50% (*M*= 962.12, *SE*=254.62*). T*he difference in dwell time between 90 and 50% images was significant *(p* =.008). However, there were no significant effects of *contingency* (10, 50 & 90%*)* on Fixation count, run count, latency and pupil change data (see table 2.22 in appendix 2)

4.12.1.2: The effect of contingency across images (goals, cues):

For the measure latency, participants were significantly faster to fixate on the *cue (M*= 1500.32, *SE*: 38.02) than the *goal (M*= 2071.30, *SE*: 72.47), *F* (1, 28) =40.74, p<.001, η^2= .59. *Contingency* had the opposite effect on pupil dilation when looking at the *goal* or *cue* (*figure 4.*19)*;* the changes to in reaction to the *cue* and *goal* was significantly different at 10% (p< .001) and 90% *(p* < .001). When fixating on CS10 the pupil constricted *(M*= -3.78, *SE*=0.92), conversely, when

fixating on the *goal10*, the pupil dilated, *(M*= 4.05, *SE*= 1.19, *p*< .001). The same pattern is observable at 90%, the pupil constricted in response to the *CS90 (M*= -3.39, *SE*= 0.90) but dilated for the *goal90 (M*= 1.83, *SE*= 1.06).For the *goal,* the pupil was significantly larger during a goal10 than goal90 (*p*= .003) and goal50 (*p*= .003) trial.

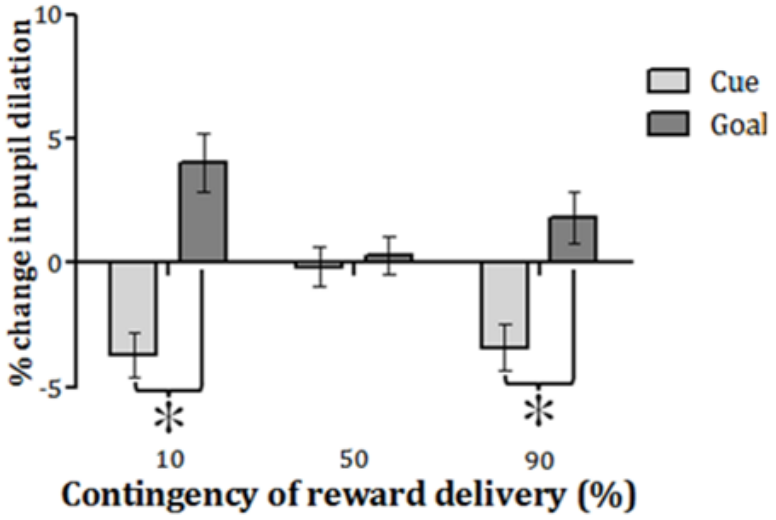


Figure 4.19: The effect if image and contingency on % change in pupil dilation *Asterisks denote significant differences (error bars show ± S.E)

There was a significant interaction between contingency and image for fixation count, *F* (1.62, 45.45) =5.15, *p* =.014, η^2= .16 (*figure 4.*20A), latency *F* (2, 56) =3.96, *p*= .025, η^2= .12 (*figure 4.*20C), run count *F* (2, 56) =4.12, *p*=.021, η^2= .13 (*figure 4.*20D) and percentage pupil change, *F* (2, 56) =15.60, *p*<.001, η^2= .36.

On the goal, fixations increased with contingency from goal10 to goal50 and significantly increased for goal90 *(p* =.021) (*figure 4.*20A). The same pattern of responding to the goal was observed for the measure run count (*figure 4.*20B). The latency to fixate was shorter at goal90 and goal10 compared to goal50 (*figure 4.*20C).

For cue, fixations were highest at CS50 decreased slightly at CS10 and were lowest at CS90 but none of the differences were significant (*figure 4.*20A). The most runs were completed into the CS10 followed by CS50 and finally CS90; the exact opposite of the goal (*figure 4.*20B). Latency to fixate was shortest at CS50 but very similar at CS10 and CS90 (*figure 4.*20C).

There was no significant interaction between image and contingency for dwell time, participants spent the longest duration dwelling on the CS10, followed by CS50 and finally CS90. *Contingency* had the opposite effect on dwell times for the *goal,* participants dwelt for the longest duration on the goal90, then goal50 and then goal10 (*figure 4.*20B).

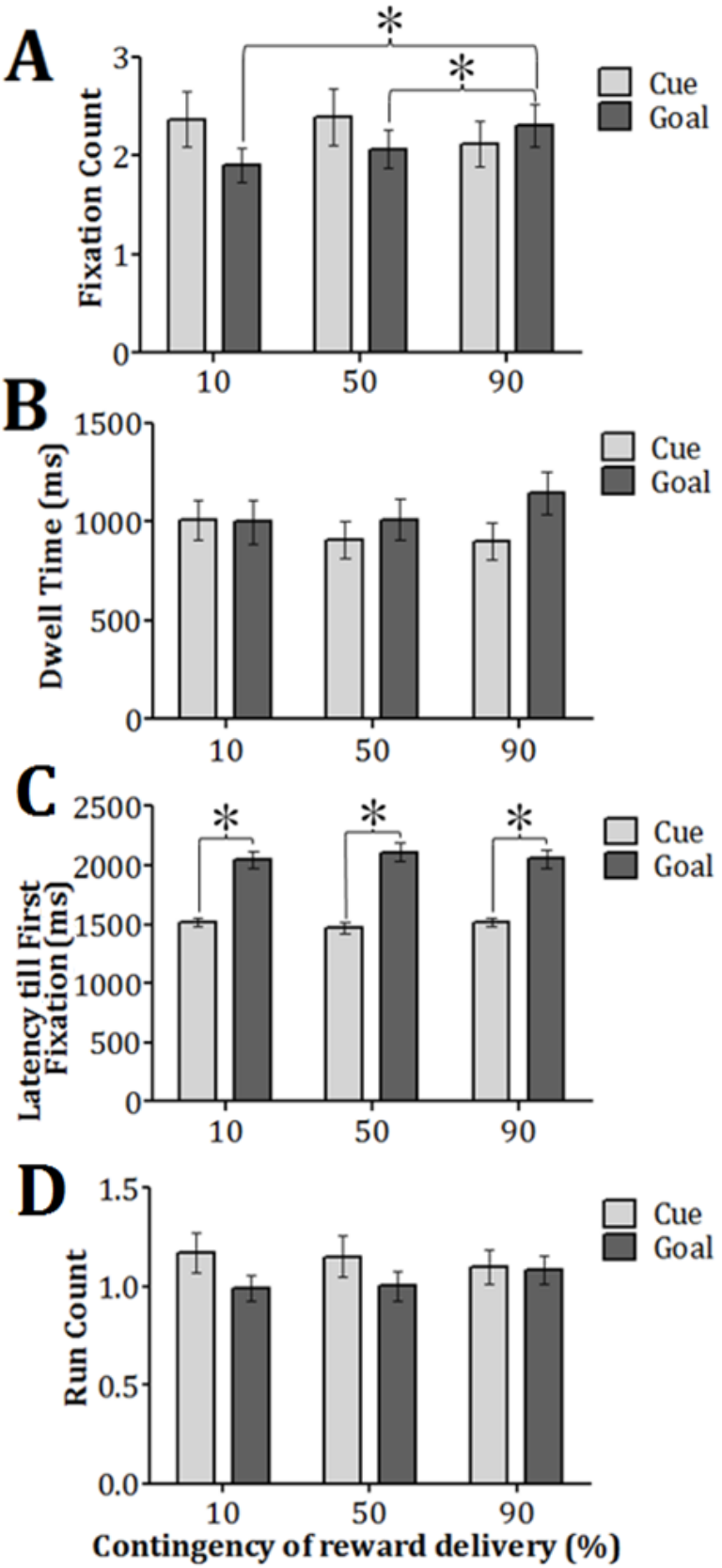


Figure 4.20: shows the interaction between the variables *contingency* and *image* for the variables fixation count **(A),** dwell Time **(B),** run count **(C**) latency **(D).** *Asterisks denote significant differences (error bars show ± S.E)

4.12.1.3: Awareness:

There was a significant effect of *stimuli*, F (2.21, 59.62) =27.64, p<.001, partial η^2= .51; the CS90 was rated as significantly more likely to be paired with reward (M= 61.92, SE= 2.40) than CS50 (M= 43.51, SE= 2.47, p <.001), but CS50 significantly more so than CS10 (M= 26.16, SE= 2.88, p <.001). There was no difference in ratings of the *goal* (M= 57.53, SE= 3.33) and CS50.

There was a significant interaction between *awareness* and *stimuli, F* (2.21, 59.62) =14.52, p <.001, partial η^2= .35. *Aware* participants rated the CS90 as significantly more likely to be followed by reward than the CS10 (p<.001); whereas, *unaware* participants rated all stimuli were rated similarly. A*ware* participants rated the CS90 as significantly more likely to be followed by reward than *unaware* participants, t (27) =6.71, p <.001, and the CS10 was rated as significantly less likely to be followed by reward by *aware* participants than *unaware*, t (27) =-4.392 p <.001(see *figure 4.*21).

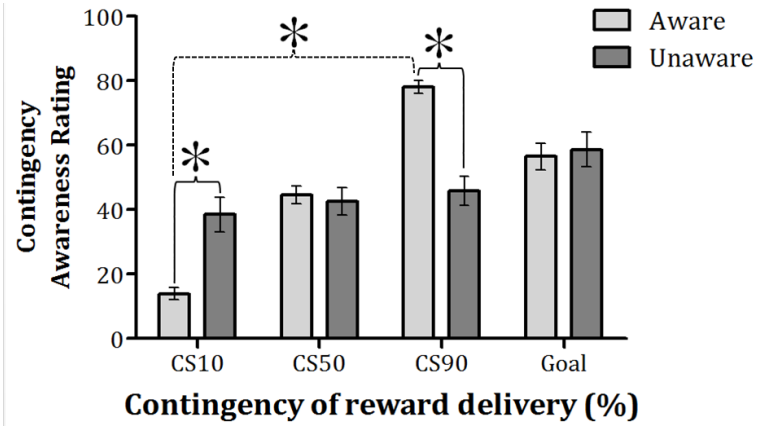


Figure 4.21: shows the contingency ratings of stimuli split by *awareness* classification (error bars show ± S.E) Asterisks denote significant differences: solid line between awareness classifications, dashed line within awareness classifications.

4.12.1.4: The effect of contingency awareness on eye-tracking measures:

The influence of *contingency* and *awareness* were then assessed for each of the eye-tracking variables. There were no significant main effects of awareness or interactions between contingency and awareness.

4.12.1.5: the effect of awareness on evaluative conditioning:

A two way ANOVA was used to determine whether *pleasantness* and/or *anxiety* ratings of the stimuli, (cue/goal10, cue/goal50 and cue/goal90) differed across *awareness* classifications**.**

4.12.1.5.1: Pleasantness:

Analysis revealed that there was no significant difference in ratings of pleasantness (0-9) across *stimuli* irrespective of *awareness* (see *figure 4.*22A)

4.12.1.5.2: Anxiety:

Results revealed a significant effect of *contingency* on ratings of *anxiousness,* which was unrelated to *awareness* classification, F (3, 78) =3.13, p=.030, partial η^2= .11. As shown in *Figure 4.*22B, CS10 induced the highest anxiety score (M= 2.67, SE= 0.34) followed by the CS50 (M= 2.55, SE= 0.31), then CS90 (M= 2.38, SE= 0.25), and finally the goal (M= 2.05, SE= 0.26, p= .013).

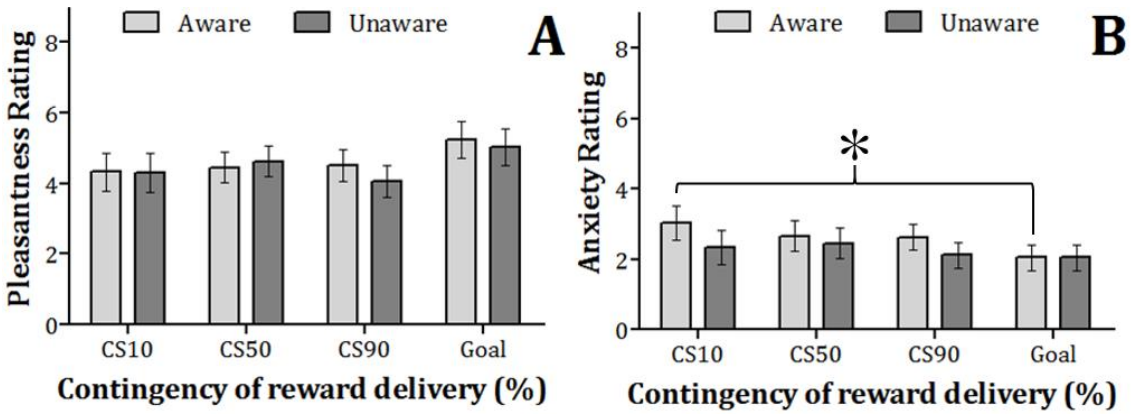


Figure 4.22: shows evaluative conditioning variables, **(A):** pleasantness, **(B):** anxiousness, split by *awareness* classification (error bars show ± S.E) Asterisks denote significant differences across *awareness* classification.

4.12.2: Section 2: Pavlovian Conditioned Gaze

4.12.2.1: the differences in eye-tracking measures across PCG classifications

According to the PCG, 6 participants were classified as *Goal-trackers,* 5 were classified as *sign-trackers* and 18 were classified as *intermediate.* The aim of this section is to elucidate how these classifications differ behaviourally, in terms of their *awareness and* across questionnaire measures.

There was a significant effect of *PCG classification* on latency, F (2, 26) =4.66, p= .019, partial η^2 =.26; *sign-trackers* (M=1983.97, SE=83.06) were slower to fixate on either image than *goal-trackers* (M=1641.67, SE=75.85). There was a significant effect of image for run count, F (1, 26)

=5.66, p= .025, partial η^2=.18 and latency, F (1, 26) =84.19, p< .001, partial η^2=.76 and percentage change in pupil size, F (1, 26) =4.69, p =.040, partial η^2=.15. Participants had a significantly shorter latency to fixate on the *cue* (*M*= 1497.35, *SE*= 36.99) than the *goal* (*M*= 2068.32, *SE*= 71.55) and returned to it (run count, *M*= 1.14, *SE*= 0.50) significantly more often than the goal (*M*= 1.03, *SE*= 0.36). In response to the *cue* participants' pupils dilated (*M*= 2.05, *SE*= 0.62) whereas, pupils constricted when fixated on the *goal (M*= -0.67, *SE*= 1.18).

There was a significant interaction between *image* and *block* on fixation count, F (5,130) =2.39, p =.042, partial η^2=.08 and percentage pupil change, F (2.3, 60.26) =6.86, p =.001, partial η^2=.21. Fixations on the *cue* did not differ across *blocks* but fixations on the *goal* were significantly lower during *block 4* (*M*=1.91, *SE*=0.99) than *block 6* (*M*=2.38, *SE*=1.22). Across *blocks,* there was a tendency for pupils to dilate in response to the *goal* but constrict in response to the *cue (*see *figure 4.*23*).*

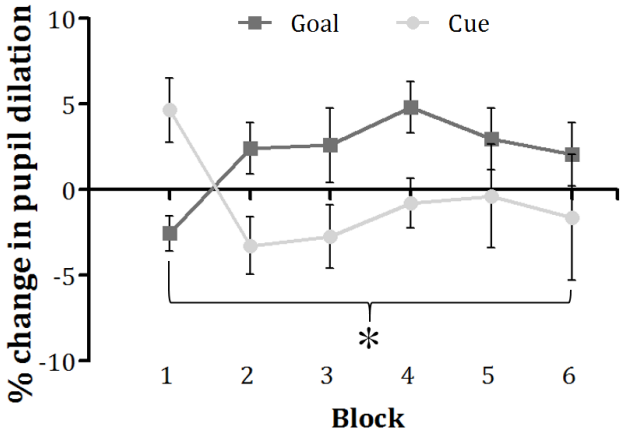


Figure 4.23: shows the average change in pupil dilation on presentation of the *cue* or *goal* across *contingency* across *blocks* (error bars show ± S.E)

There was a significant interaction between image and PCG classifications for dwell time, F (2, 26) =79.58, p< .001, partial η^2=.86, run count, F (2, 26) =79.58, p< .001, partial η^2=.18 and latency, F (2, 26) =18.06, p< .001, partial η^2=.58. Goal-trackers dwelt on, completed runs into and had a shorter latency to fixate on the goal than the cue. Conversely, sign-trackers and intermediates dwelt on, completed more runs into and were faster to fixate on the cue than the goal.

Finally, for fixation count there was a significant interaction between *PCG classifications*, images and blocks, F (2, 26) =45.83, p< .001, partial η^2 = .78 (see *figure 4.*24i); *sign-trackers* (M= 4.16, SE= 0.44) completed significantly more fixations into the *cue* than the *intermediate* (M= 2.27, SE= 0.23, p= .016) and *goal-trackers* (M= 0.84, SE= 0.41, p< .001), F (2, 26) =15.26, p< .001, partial η^2 =.54 (*figure 4.*24iA). In addition, *goal-trackers* (M= 3.18, SE= 0.31) completed significantly more fixations on the *goal* than the *intermediate* (M= 1.98, SE= 0.18, p= .008) and *sign-trackers* (M= 0.84, SE= 0.41, p= .001), F (2, 26) =9.69, p= .001, partial η^2 = .43 (*figure 4.*24iB).

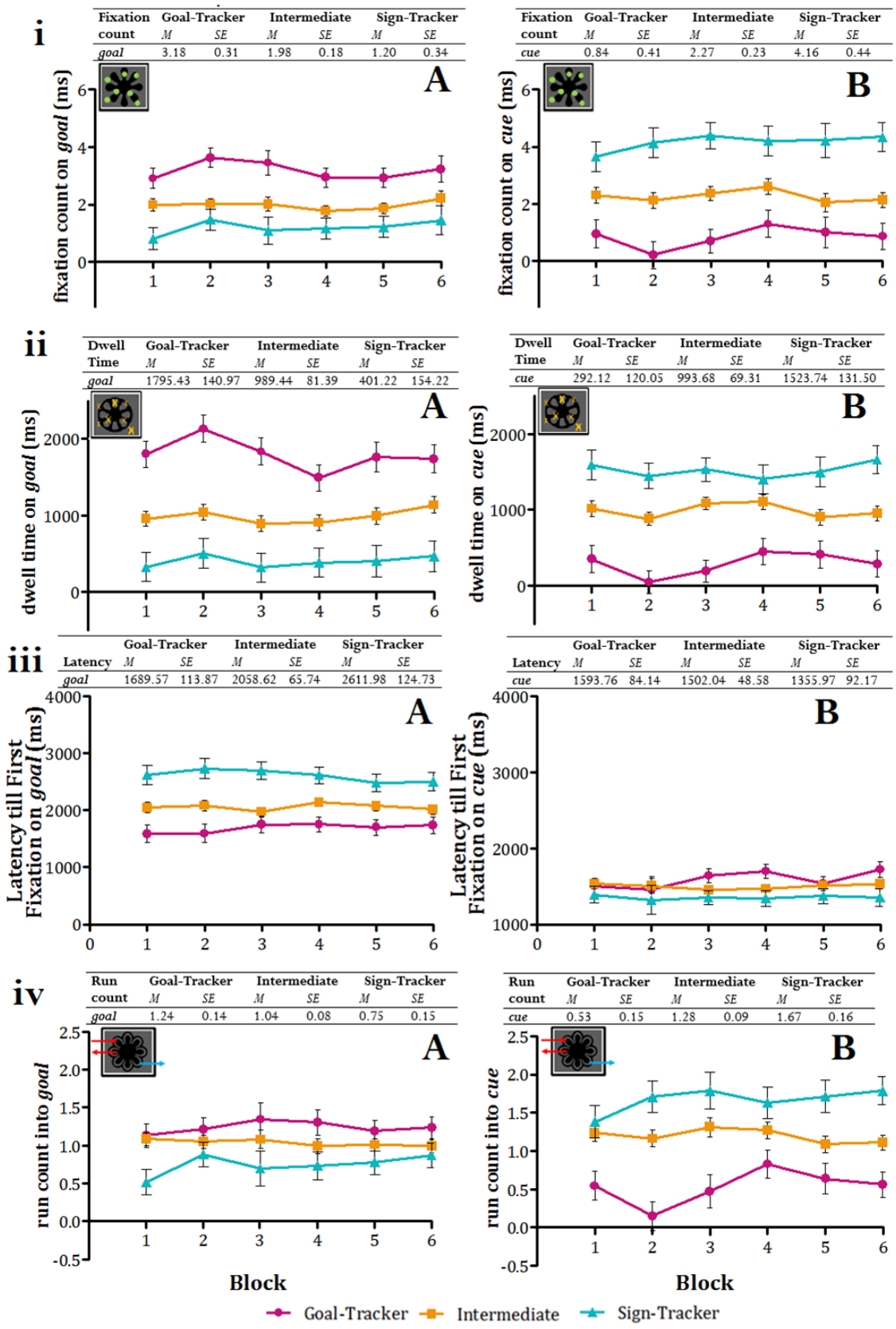


Figure 4.24: shows **(i)** fixation count, **(ii)** dwell time, **(iii)** latency and **(iv)** run count across *block* split by *image, goal* **(A)** and *cue* **(B)**, and *PCG classification* (error bars show ± S.E; note what small tables show).

	Goal-Tracker		Intermediate		Sign-Tracker	
	M	***SE***	***M***	***SE***	***M***	***SE***
Fixation count						
Cue	0.84	0.41	2.27	0.23	4.16	0.44
Goal	3.18	0.31	1.98	0.18	1.20	0.34
Dwell Time						
Cue	292.12	120.05	993.68	69.31	1523.74	131.50
Goal	1795.43	140.97	989.44	81.39	401.22	154.42
Run Count						
Cue	0.53	0.15	1.28	0.09	1.67	0.16
Goal	1.24	0.14	1.04	0.80	0.75	0.15
Latency						
Cue	1593.76	84.14	1502.04	48.58	1355.97	92.17
Goal	1689.57	113.87	2058.62	65.74	2611.98	124.73

Table 4.15: displays the means and SE for each *Pavlovian conditioned gaze classification* split by *image*

4.12.2.2: the relationship between PCG classification and awareness:

Analysis on overall *goal* and *cue* fixation count, dwell time, latency and, run count no significant interactions between *awareness* and *Pavlovian conditioned gaze classifications* (*ps* < .475, see table 2.23 in appendix 2. Table 2.24 in appendix 2 shows non-significant interactions between contingency, awareness and PCG class and table 2.25 in appendix 2 shows non-significant interactions between contingency, awareness, image and PCG class on overall eye-tracking measures).

As before Chi-square revealed no relationship between *PCG classification* and *awareness,* χ^2 (2) =.166, *p* =.920 and odds ratios are shown in *table 4.16*.The results support experiment 4.1 showing that sign-trackings are marginally more likely to be aware of reward contingencies than goal-trackers.

PCG classification	**Odds ratio:**	**% *Aware* participants**	
	Aware	**Within *PCG class***	**In other *PCG classes***
Sign-tracker	1.50	60.0	50.0
Intermediate	0.83	50.0	54.5
Goal-tracker	0.92	50.0	52.2

Table 4.16: shows odds ratios for being designated *aware* and proportions of *aware* participants across *PCG classifications*

4.12.2.3: Evaluative Conditioning by PCG classification:

In terms of evaluative conditioning, there was no significant difference in the ratings of pleasantness or anxiousness of stimuli across *image, contingency* or *Pavlovian conditioned gaze classifications.* Analysis was then conducted including awareness; however, revealed no significant differences or interactions (see table 2.26 appendix 2).

4.12.2.4: The effect of contingency between PCG classifications

There were no significant interactions between PCG classifications and contingency for any of the eye-tracking measures (dwell time, fixation count, run count, latency or percentage pupil change)

4.12.2.5: The effect of contingency across image between PCG classifications

The influence of *image* and *contingency* were then examined across *PCG classifications* for fixation and run count, dwell time, change pupil dilation and latency; there were no significant effects or interactions for any measures (see *table 4.*17 for values).

4.12.2.5.1: Comparing the effect of contingency on eye-tracking measures on the Cue across PCA classifications.

For fixation count, intermediates fixated most on the CS90, whereas sign-trackers fixated most on the CS50 and goal-trackers on CS10. Sign-trackers and intermediates fixated on the CS10 least. The same pattern of responding is observed in the measure run count. For dwell time, *intermediates* dwelt on the CS90 for longer than CS50 and CS10; whereas, both *sign* and *goal-tracker*s dwelt on the CS10 for longest and the CS50 least. *Intermediates* and *sign-trackers* were also fastest to fixate on the CS50, although *sign-trackers* were slowest to fixate on the CS90 and *intermediates* were slowest to fixate on the CS10. *Goal-trackers,* however, were fastest for CS90 followed by CS50 and finally CS10 (see *table 4.*17).

4.12.2.5.2: Comparing the effect of contingency on eye-tracking measures on the Goal across PCA classifications.

Participants completed the most fixations, had the longest dwell time and completed more runs into the goal10 than goal50 and goal90. *Sign* and *goal-tracker*s dwelt on the *goal90* for longer than the *goal50* but the reverse is true for *intermediates. Latency* to fixate was slowest at goal50 for all *PCG classifications,* but *intermediates* and *sign-trackers* fixated on the goal90 faster than the *goal10,* whereas the reverse was true for *goal-trackers* (see *table 4.*17).

	CUE						GOAL					
	CS10		CS50		CS90		CS10		CS50		CS90	
	M	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***
Fixation count												
Goal-Tracker	0.98	0.36	0.78	0.46	0.78	0.49	3.44	0.40	3.19	0.32	2.98	0.30
Intermediate	1.99	0.21	2.37	0.27	2.43	0.28	2.21	0.23	1.98	0.19	1.73	0.17
Sign-Tracker	3.97	0.39	4.48	0.51	4.08	0.53	1.30	0.44	1.07	0.35	1.24	0.33
Dwell Time												
Goal-Tracker	320.79	133.18	268.56	130.25	295.38	151.9	1832.34	160.17	1749.84	153.68	1799.14	158.23
Intermediate	909.10	76.84	965.09	75.20	1109.23	87.7	1113.79	92.48	953.71	88.73	893.33	91.35
Sign-Tracker	1581.52	145.79	1477.69	142.69	1522.57	166.48	438.70	175.46	353.18	168.34	427.53	173.33
Latency												
Goal-Tracker	1634.94	72.16	1626.67	108.85	1623.09	78.45	1666.37	128.88	1723.27	115.55	1686.17	113.93
Intermediate	1520.34	41.66	1466.28	62.84	1509.28	45.29	2034.93	74.41	2091.06	66.71	2019.58	65.78
Sign-Tracker	1351.87	79.05	1303.89	119.24	1403.68	85.94	2601.37	141.18	2650.55	126.58	2573.70	124.88
Run Count												
Goal-Tracker	0.61	0.15	0.47	0.16	0.53	0.16	1.27	0.16	1.26	0.15	1.16	0.14
Intermediate	1.13	0.08	1.23	0.18	1.24	0.09	1.10	0.09	1.02	0.09	0.99	0.08
Sign-Tracker	1.59	0.16	1.72	0.18	1.69	0.17	0.81	0.18	0.67	0.17	0.78	0.15
Pupil change												
Goal-Tracker	-1.41	1.81	-0.70	1.78	-2.59	1.92	1.78	2.39	0.95	1.70	6.15	2.56
Intermediate	-2.68	1.04	-0.06	1.03	-2.92	1.11	2.31	1.38	0.24	0.98	4.61	1.48
Sign-Tracker	-8.32	1.98	0.21	1.95	-7.85	2.10	0.13	2.62	-0.18	1.86	-0.49	2.8

Table 4.17: shows the fixation count, dwell time, run count, latency and pupil change split by *image, contingency* and *PCG classifications* Asterisks denote significant differences, *=p<.05 *(Table 2.23 in appendix 2* shows Ms & SEs for three-way interaction awareness, contingency and PCG class, *table 2.24 in appendix 2* shows four way interaction contingency, awareness, PCG class. and image).

4.12.2.6: Comparing questionnaire measures across PCG classifications:

4.12.2.6.1: AUQ binger classification*:*

6 participants were classed as *Non-Bingers (*Binge score of 12 or less), 10 *Bingers* (binge score of 49 or more) and 13 *unclassifiable*, who were excluded for grouped analysis, but included for correlations. Analysis revealed no significant difference in *Binge* or *AUQ* score across either *PCG* or *BIS classifications (*see *table 4.*18)

		AUQ: AUQ score		AUQ: binge score	
		M	***SE***	***M***	***SE***
PCG	*Goal-Tracker*	27.65	13.41	18.33	9.52
	Intermediate	55.33	7.75	37.17	5.58
	Sign-Tracker	43.12	14.78	27.03	10.43
BIS	*Goal-Tracker*				
	Intermediate	62.98	15.14	37.4	10.78
	Sign-Tracker	43.07	7.22	28.87	5.14

Table 4.18: shows average AUQ and binge scores across *BIS* and *PCG classifications*

4.12.2.6.2: BIS classification*:*

22 participants reported *normal* levels of impulsivity, 5 reported being *highly impulsive* and, 2 reported *overly-controlled.* There were no significant differences in raw BIS score *or* the 6 *BIS subscales* (*attention, cognitive instability, motor, perseverance, self-control* and *cognitive complexity*) across PCG classifications. Finally, there was no difference in the *discounting rate* across *BIS classifications*

4.12.2.6.3: DUQ: Poly Drug Classification:

8 participants reported having never tried THC based products and 17 reported having never tried any of the other illicit substances in the DUQ. There were 17 participants who were either drug-naïve or whose only drug experience was using THC based products (henceforth referred to as *single drug*) and 12 *poly-drug users*. There were 25 *non-smokers.* 2 participants did not wish to disclose their smoking status.

There was a significant difference between poly drug and single-drug or drug-naïve participants in *AUQ* and *Binge score*. *Poly-drug* users reported a significantly higher AUQ score (*M*=38.18, *SE*=3.37) than *single-drug* participants (*M*=14.64, *SE*=3.06; F (1, 62) =27.74, p <.001, partial η^2= .30. *Poly-drug* users also reported significantly higher *binge scores* (*M=23*.58, *SE*=1.99) than

single-drug participants (*M*=23.49, *SE*=2.28; *F* (1, 62) =21.78, *p* <.001, partial η^2= .26. Results revealed no significant difference in *discounting rate* between *poly drug* and *single drug* users.

4.12.2.6.4: Discounting rates:

There was a significant effect of reward size on *discounting rate*; *F* (1.31, 33.98) =4.69, *p* =.028, partial η^2= .15. Analysis of average discounting rate revealed that participants discounted the medium rewards (*M*=0.01, *SE*=0.01) significantly faster than the large rewards (*M*=0.03, *SE*=0.01, *p* =.009). The small rewards (*M*=0.01, *SE*=0.003) were discounted significantly faster than the medium (*p* =.004) and large (*p* =.007) rewards. Though non-significant *figure 4.25* shows that goal-trackers discounted large rewards more slowly than intermediate or sign-trackers.

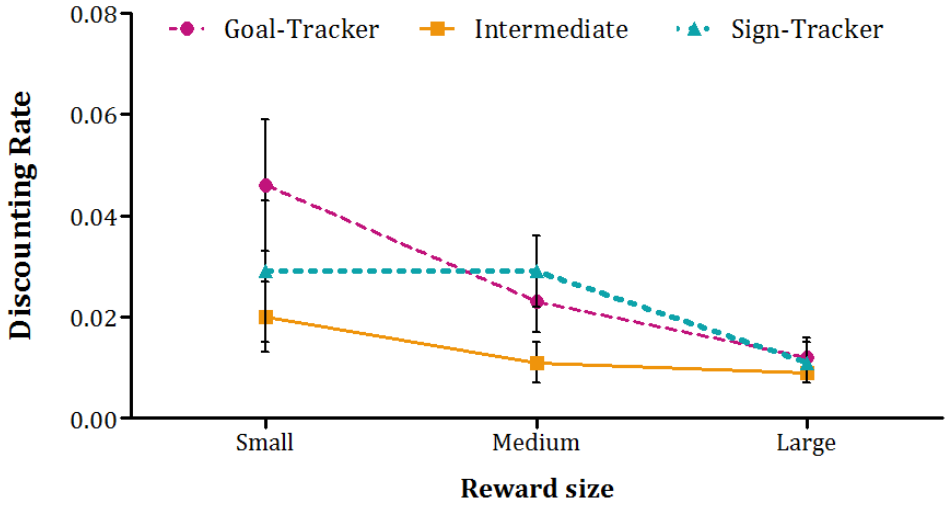


Figure 4.25: shows the average discounting rate split by Pavlovian conditioned gaze classification (error bars show ±SE)

Sample sizes within *PCG classifications* were small so odds ratios were calculated to explore alcohol/drug-use and impulsivity scores across *PCG classifications* (see *table 4.19*). Odds ratios revealed that intermediate responders were 4 times more likely to be classified as "highly-impulsive" than normal or overly-controlled. Sign-trackers showed the lowest odds of being a poly drug user.

	Binge drinker	*Poly-drug user*	*BIS classifications*		
			Highly-Impulsive	**Normal**	**Overly-controlled**
Goal-tracker	----	1.56	1.25	1.77	----
Intermediate	2.0	1.40	4.0	0.20	0.56
Sign-Tracker	1.25	0.38	1.26	----	----

Table 4.19: shows odds ratios for being, and proportions of, participants designated *binge drinkers, poly-drug users* or *BIS classifications* across *PCG classifications*

4.13: Discussion:

The three distinct Pavlovian conditioned gaze classifications were again identifiable in experiment 4.3 and demonstrated distinct eye-movements across a number of measures.
As in experiment 4.1 a consistent difference in pupil dilation on presentation of the goal or cue across training blocks. This finding supports the previous assertion that this result is due to the cognitive load of reading the reward message on the goal.

By including the distinct locations for each reward paired cue, results from experiment 4.3 showed the effect of reward contingency on behaviour more clearly than had been shown in experiment 4.1. Participants were shown to attend to the goal more as the probability of reward receipt increased but the reverse is true for the cue image. This result is supports previous research using non-human animals that has shown that sign-tracking responses are potentiated by a decline in reward probability but goal-tracking is unaffected (Boakes, 1977; Anselme, Robinson & Berridge, 2013; Robinson et al., 2015; Davey et al., 1981; Davey & Cleland, 1982). This finding supports the assertion that this methodology provides a translational equivalent to non-human models of sign- and goal-tracking; particularly as contingency effected conditioned responses in sign- and goal-tracking participants differently to intermediate responders.

The results of the evaluative conditioning analysis showed that, as in experiments 4.2 and 4.3, pleasantness ratings differed neither across levels of image (goal and cue), contingencies or PCG classifications. Furthermore, in support of experiment 4.1, there were no differences in anxiety ratings.

The questionnaire analysis did not highlight any potential markers of sign- or goal-tracker topography.

4.14: General Discussion

This series of experiments represents some of the only research to identify sign- and goal-tracking behaviour in humans. In all three experiments intermediate, sign- and goal-tracking response topographies were identified and shown to be consistent across multiple eye-tracking measures. Analysis revealed no differences in ratings of evaluative conditioning across PCG classifications, meaning that sign- and goal-tracker designations were unrelated liking. There was some evidence to suggest that sign-trackers might be more likely to acquire reward contingencies than goal-trackers; however, this result may have been produced by the small samples in each of the PCG classifications. Within the animal literature, a central specification of sign- and goal-tracking behaviour is that the stimulus (sign) or site of reward (goal) has been attributed with incentive motivational properties (Robinson & Flagel, 2009). This has been demonstrated by increased probability and reduced latency to approach the reward source (goal-trackers) or cue (sign-trackers) (Flagel et al., 2008). This was confirmed in the present set of experiments, as sign and goal-trackers showed shorter latencies to fixate on their respective preferred images.

Pupil size was recorded for all three experiments to assess arousal, as it has been proposed that pupil dilation is influenced by emotion and cognitive load. Experiments 1 and 3 showed that pupils dilated in response to the goal and not the cue. In experiment 4.2, this effect was more pronounced at 50%, when a reward message appeared across the goal50 but not the goal0 image. Combined, these results suggest that the pupil dilation observed in all 3 experiments was the result of the increased the cognitive load of reading the reward message on the goal images.

A recent study by Garofalo & di Pellegrino (2015) was one of the first to demonstrate sign- and goal-tracking in humans and did so using an appetitive Pavlovian Instrumental Task (PIT) and an eye-tracker. However, the protocols from the current experiments differed from Garofalo & di Pellegrino (2015) in a few important ways. Firstly, in Garofalo & di Pellegrino's (2015) procedure, neither the cue images nor the spatial locations of the goal and cue were counterbalanced; therefore, it is not possible to eliminate the possibility that sign- and goal-tracking was not the result participants' preference for particular images or locations on screen. Secondly, the current experiments used a number of eye-tracking measures to verify that the bias observed in dwell time was reliable; whereas, Garofalo & di Pellegrino (2015) reported dwell

time alone. Thirdly, self-report measures of contingency awareness and evaluative conditioning of stimuli were included in the current protocol, allowing us to assess whether the conditioned responses were the result of knowledge of probabilities and to assess for a dissociation between wanting and liking. Finally, the current experiments aimed to investigate whether reward contingency altered sign- and goal-tracking behaviour by presenting recognizable cues with three distinct reward probabilities; whereas, Garofalo & di Pellegrino (2015) compared two; 0 and 80%.

The includion of contingency of reward receipt was a key factor in all three of the current experiments as it allowed for the examination of models of attention and the effect of uncertainty on PCG topographies.

The results from these experiments were examined within the frameworks of the Pearce-Hall (Pearce et al., 1980) and Mackintosh (1975) theories of attention. Across all three experiments the only significant effect of contingency alone was in experiment 4.3 and showed that dwell times were significantly longer on the 90% images (goal and cue combined) than either 50 or 10% images; this result provides support for the Mackintosh theory of attention, that the higher the contingency of reward receipt the more attention is captured.

When analysis was split by image and reward probability, the results became more difficult to interpret. Firstly, attention to the cue was examined. In experiment 4.3, when location was introduced (see *figure 4.*26iii), the CS10 was attended to in excess of C50 and CS90, which is inconsistent with both the Pearce-Hall and Mackintosh models. By contrast, during experiments 1 and 2, although not reaching significance in either case, dwell time on the CS50 was the longest in duration and, in experiment 4.2, fixation count on CS50 as significantly higher than CS0. If the CS50 is understood to represent probabilistic uncertainty, then this effect lends support to the Pearce-Hall model, which proposes that the more uncertain a stimulus is, the more attention it receives. However, if CS50 is framed positively, as a 50% contingency of reward receipt, then this result supports Mackintosh.

Attention on the goal was also allocated differently across experiments. In experiment 4.1, dwell time on the goal decreased as probability of reward receipt increased, whereas the opposite was true in experiment 4.3 and an attentional bias towards the goal90 was observed for all eye-tracking measures. These results are difficult to interpret; one possible explanation is that, in

experiment 4.1, attention is captured by the unpleasant written message on the goal10. As experiment 4.3 was a more complex design (see *figure 4.*26iii), the cue provided information about reward probability and where attention should be directed; whereas, due to being paired with reward, the goal acquired a positive valence. On presentation of a highly predictive cue for reward (CS90), participants are motivated to look at the goal90, as it was associated with positive emotions. While, on presentation of the CS10, participants were not motivated to attend to the goal, as the presented cue lacks positive associations with reward. This assessment is supported by a post hoc examination of the dwell times on the goal and cue across blocks showed that, at 10 and 50% probability, dwell times on the cue and goal were the same across blocks, i.e. across time. At 90%, dwell times were biased towards the goal across blocks (see appendix 2: figure 2.1)

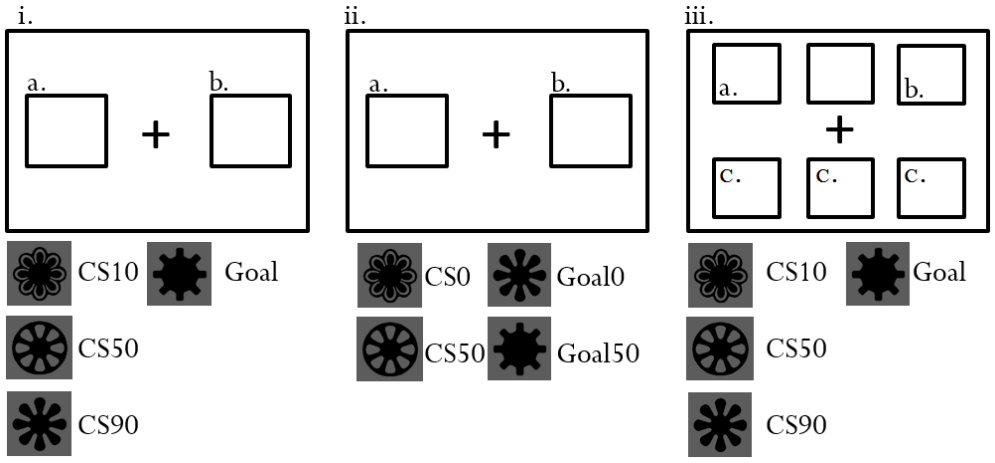


Figure 4.26: shows the layout of the screen for experiments 1 (i), 2 (ii) and 3 (iii). For experiments 1 and 2 a and b denote locations of cue and goal images (shown below each 'screen', for experiment 4.3 a and b represent the locations of the CS10 and CS90, the middle square as always CS50 and c shows the location of the corresponding goal images.

By including the distinct locations for each cue in experiment 4.3, the eye-tracking response measures increased, compared to experiment 4.1; for example, average dwell time in experiment 4.1 (M=188.99 SE=10.06) was over five times shorter than in experiment 4.3 (M=997.69 SE=48.24). This increase in eye-movements indicates that participants were more engaged in the task in experiment 4.3 than experiment 4.1. Brandt & Stark (1997) provided evidence that eye-movements reflect the content of the visual scene; suggesting that the increased eye-movements in experiment 4.3, compared to experiment 4.1, might be due to the increased complexity of the screen (see *figure 4.*26). An alternative explanation for this is that the location, goal and cue images became a compound stimulus. This would mean that the increase in eye movements

reflects a kind of hypothesis testing, wherein, participants were trying to learn the associations between the images, the sequence they appeared in and their location, in order to ascertain the circumstances under which they could expect receive a reward.

The effect of contingency was then assessed across PCG classifications, as animal models of sign- and goal-tracking have demonstrated that conditioned response topographies are differentially effected by reward probability (Davey et al., 1981; Davey & Cleland, 1982); with sign, but not goal,-tracking responses being enhanced by reward uncertainty (Anselme et al., 2013; Robinson et al., 2015). The results of experiment 4.1 showed some support for this, as all PCG classifications completed more fixations into the CS50 than CS10 and CS90. Similarly, goal and sign-trackers had the longest dwell time on the CS50. While experiment 4.3 failed to replicate these findings; latency till first fixation was shortest for the CS50 for both intermediate and sign-tracking participants.

It has been suggested that decision utility reflects the incentive salience or "wanting" of a reward, whereas experienced utility describes liking (Berridge & O'Doherty, 2014). In experiments 4.1 and 4.3, no difference in anxiety ratings across images or contingencies was observed. In experiment 4.2, the goal50 image was rated as producing significantly more anxiety than the goal0. The hypothesised reason for this is that the predicted/remembered utility of the goal50 was uncertain. By contrast, there were no differences in pleasantness ratings across images, contingencies or PCG classifications in experiment 4.1, 4.2 or 4.3. This means that, despite directing their attention to either the goal or the cue, goal- and sign-trackers do not necessarily like their attended to images more than the other. Sign-tracking has been described as resulting from a transient increase in decision utility in excess of predicted/remembered utility (Berridge & Alridge, 2008). A possible avenue for further investigation would be to change the way feedback is provided to participants so as to be able to identify the moment when this increase occurs more accurately, as from the current protocol it is unclear whether this occurs when the images are presented together (Figure 4.3c) or when feedback appears onscreen (figure 4.3d).

The results of these experiments demonstrated that PCG was influenced by context. During experiment 4.1, irrespective of reward probability, the cue was attended to in excess of the goal; however, in experiment 4.3, once location was introduced, attention was divided more equally across goal and cue. This supports the assertion by Moore & Stickney (1982) that goal-tracking is more dependent on contextual stimuli than sign-tracking. Further to this, proportions of PCG

classifications were then compared across experiments and, while the proportion of intermediates remained equal, the number of sign-trackers decreased and goal-trackers increased in experiment 4.3 compared to 1. Importantly, comparison of the contingency awareness ratings confirmed that participants' knowledge reward probabilities did not differ across experiments; meaning this shift in attentional allocation was not due to awareness.

Research using animal models has found evidence for the assertion that sign-trackers are more impulsive than goal-trackers (Tomie, 1996; Lovic et al., 2011; Olshavsky et al., 2014). In order to assess whether this was also true in humans, impulsivity was assessed using the BIS and Kirby et al., (1999) discounting questionnaire. Results showed there was no difference in discounting rates across *PCG classifications* suggesting that impulsivity levels did not vary across behavioural groups. This result is contradictory to results from animal research (Tomie et al., 1998; Flagel et al., 2010; Lovic et al., 2011), though a possible explanation for this is that the delay discounting paradigms utilised in animal models are set over a much reduced time frame compared to the Kirby et al. (1999) questionnaire. In addition to this, the Kirby et al. (1999) uses money as a reward which is a secondary reinforcer which can be stored and converted into other rewards, and discounting is known to be effected by reward type (Bickel et al., 2011). Research has demonstrated that humans demonstrated significantly faster discounting when presented with food rewards, rather than monetary rewards (Rosati, Stevens, Hare &Hauser, 2007). Which means the Kirby et al. (1999) questionnaire might reflect a more conservative estimation of discounting rate than the task performed by the animals. Results from the current experiments also revealed no difference in BIS-11 score across PCG classifications. One possible explanation for this is the low number of sign and goal-trackers identified in each experiment. Alternatively, impulsivity is a multi-faceted construct (Caswell, 2013), so it is possible that the BIS-11 failed to identify subtle differences in the impulsivity levels across PCG classifications.

Questionnaire measures, DUQ and AUQ, were also utilised to examine whether PCG classifications were associated with a propensity to substance abuse or alcohol consumption, as has been demonstrated using animal models (Tunstall & Kearns, 2015; Robinson et al., 2014). While results from experiments 1 and 2 showed that impulsivity, as measured by the BIS-11, is associated with increased drinking and binge drinking (Papachristou et al., 2012), no relationship between alcohol consumption and sign or goal-tracking behaviours was observed in the current experiments. Although, this measure was included on an exploratory basis and participants were not selected based on previous drug use; consequently, this result might be due to the cohorts

recruited for the experiments. A future direction for such research would be to examine the differences in proclivity to attend to the goal or the cue across drug-naïve and substance-abusing participants.

One shortcoming of the methodology used in these experiments is that eye-tracking equipment has a tendency to become uncomfortable over the course of a session, meaning that the duration of the procedure in the current experiments was limited by this factor. In non-human animal models, a training protocol is usually completed before test, as animals take markedly longer to acquire a conditioned responses than humans. Inclusion of such a training program, using the same stimuli as the sign- and goal-tracking procedure, might help differentiate behaviour.

Another issue with the present design that it was not possible to use the PCA index (Meyer et al., 2012) to designate of participants as intermediates, sign or goal-trackers. The PCA index was calculated for dwell time for the 3000ms the *cue* and *goal* were presented together (see tables in appendix 2). Across experiments, nearly all the scores fell between the benchmarks of -.49 and .49, classifying them as intermediate responders (Meyer et al., 2012). For this reason, the PCG classification was developed in order to assign participants to groups. A potential explanation for why our protocol did not polarise responding sufficiently to produce sign and goal-trackers according to the PCA index (Meyer et al., 2012), as Garofalo & di Pellegrino's (2015) investigation did, is that there were three reward probabilities in the current experiments. This means that the associations in the current task would have been more difficult to learn than binary relationship in Garofalo & di Pellegrino's (2015) paradigm. In addition to this, during two stages of Garofalo & di Pellegrino's (2015) protocol participants had to make a response, as quickly as possible, in order to find out whether an image had been rewarded or not. This may have encouraged participants to engage their attention more than in the current experiment, meaning that they acquired the association between the cues and reward more readily than participants in the current investigation.

Lastly, chin rests were not used in any of these experiments and there was no opportunity within the program to take a baseline reading of pupil size, which means that the percentage change in pupil dilation measure was calculated by averaging all pupil measurements and calculating pupil size as a change from this baseline. Future investigations should include such adjustments in order to confirm the interpretation of pupil size already discussed.

Chapter 4: sign- and goal-tracking in humans

- This series of experiments reliably identified intermediates, sign- and goal-trackers within a human sample
- Inclusion of the evaluative conditioning and awareness ratings support the assertion that Pavlovian conditioned gaze classification is distinct from liking and awareness.
- The effect of contingency across images varies across experiments. In experiment 4.1 the lower the reward contingency the higher goal-directed behaviours and higher reward contingency the more sign-directed behaviours. In experiment 4.3, the higher the reward contingency the greater the number of goal-directed behaviours. When reward receipt was least predictable sign-directed behaviours were highest.
- This shift in response type is attributed to the increased contextual cues in experiment 4.3
- Pupil dilation data revealed that participants' pupils dilated more when looking at the goal than the cue
- There were no significant differences in discounting rates, impulsivity levels, drug use, alcohol use between Pavlovian conditioned gaze classifications

5. Devaluation of Probability and Delay-discounting in C57/BL Mice

Abstract:

There is ample evidence that the inability to exert self-control and relinquish immediate, small rewards in preference for more substantial, delayed rewards predicts negative outcomes in later life. Using a within subjects design this behaviour is modelled by probability and delay-discounting paradigms using 16 C57BL mice. Animals were trained using probability and delay-discounting paradigms, the sucrose reinforcer was then devalued two hours before test. The mice reliably acquired both discounting behaviours. Analysis showed that the behaviour acquired during delay-discounting promoted responding on the established probability-discounting behaviour. Pre-exposure to reward had a significant effect on probability, but not delay, discounting behaviour. This results suggests, in line with previous findings, that probability and delay-discounting are part of a larger multifaceted construct rather than a reflection of the same underlying process. However, reversed presentation order in delay-discounting indicated that observed behaviour may have been the result of order effects.

Keywords: Probability-discounting, delay-discounting, order of presentation, framing, devaluation

When presented with a choice, an agent will use their previous experience to assess the subjective cost and potential reward of each option (Floresco, Tse, & Ghods-Sharifi, 2008). Whilst the value of the reward, utility, can be influenced by a number of factors (Holt, Green, & Myerson, 2003), such as physiological state (Acheson, Richards, & de Wit, 2007; Minamimoto, Hori, & Richmond, 2012) or reward quantity, the relative subjective cost can be altered by factors such as uncertainty or delay (Blackburn, Mason, Hoeksma, Zandstra, & El-Deredy, 2012; Burke, Brünger, Kahnt, Park, & Tobler, 2013). This means that the longer a reward is withheld, or the more uncertain its receipt is, the greater the reduction in utility. When the size of an immediate reward is deemed equivalent to a delayed reward this is called the "present-value" of the delayed reward (Rachlin, Brown, & Cross, 2000). The paradigms of delay and probability-discounting are used in order to assess how reward present-value can be influenced by systematic variation along

two dimensions i.e. the size of the reward and either the delay to or likelihood of reward receipt, respectively (Cardinal, Robbins, & Everitt, 2000; Green & Myerson, 2004).

Delay- and probability-discounting paradigms, used in both animal and human research, ultimately consist of a choice procedure. In delay-discounting, participants are asked to choose between a small-immediate reward and a large-delayed reward; the length of the delay, or the size of the reward, is then gradually varied to determine when the present value of the delayed and immediate reward is equivalent. A probability-discounting procedure is carried out in much the same way except the systematic variation is applied to the likelihood of receiving the large reward. When the delay before, or probability of, reward receipt is only slight, the advantageous choice in such a paradigm is obvious: the present value of the smaller reward is less than the larger reward. However, as the delay approaches infinity (or the probability approaches zero) the present value of the larger reward decreases which leads to an *indifference point* and eventually a *preference reversal* (Rachlin et al., 2000; Reynolds, 2004).The rapidity with which an individual reaches this indifference point is said to reflect how "self-controlled" they are; those who are unable to relinquish more immediate but less satisfying rewards, in preference for delayed substantial rewards, are said to be "impulsive" (Ainslie, 1975; Cardinal et al., 2000; Evenden, 1999; Evenden & Ryan, 1996, 1999).

A procedural variant shown to influence discounting rate in humans is the order in which the choices are presented (Andersen, Harrison, Lau & Rutstrom, 2006); with discounting rates being least impulsive when delays until reward receipt are presented in an ascending order as opposed to a descending (Robles & Vargas, 2008; Robles, Vargas, & Bejarano, 2009) or random order (Robles & Vargas, 2007). This manipulation has been replicated using rat models of delay-discounting; some results showing no difference in discounting rate as a result of delay presentation order (Slezak & Anderson, 2009) or, that descending orders produce more rapid discounting than either ascending or random sequences (Fox, Hand, & Reilly, 2008). A potential explanation for the rapid discounting observed with a descending delay sequence is the nature of the discounting tasks themselves. When an agent selects between a small immediate reward and a large-delayed-reward, they are deciding between a good-reward directly and a better-reward later. Previous experimental research has established that how alternatives are framed can significantly influence the subsequent decisions, even if the frames are logically equivalent (Tversky & Kahneman, 1981; 1991). Framing effects influence behaviour through a tendency to over-weigh (loss-aversion) or under-weigh (risk-seeking) the possibility of losing. Previous

research has shown that in delay-discounting adjusting-amount procedures individuals tend to switch earlier when the amount of immediate reward declined with each trial, and later when the size of the immediate reward increased with each trial (Robles & Vargas, 2008). Therefore, if the decision is one in an ascending or descending delay sequence, participants will have experience of responses within the series and consequently, may, if they compare their current reward and delay options with those presented on previous trials (Lockhead, 2004), perceive the outcomes in terms of potential gains or losses (Robles & Vargas, 2007). For example, if an individual is making a decision in an ascending cost sequence, each subsequent decision the cost (or delay) will be higher when compared to the previous choice this could be perceived as a loss. Conversely, in a descending sequence the delay before reward receipt would decrease with each decision, which might be perceived as a gain. This means that even if overall reward is the same, individuals might react differently as a result of how the options are framed within a choice sequence.

Whilst rapid responding to environmental stimuli is not necessarily maladaptive (Dalley, Everitt, & Robbins, 2011), research into impulsivity has found this trait to be prevalent in certain psychiatric and addictive disorders including risky sexual behaviours (Caspi et al., 1997; Horvath & Zuckerman, 1993), ADHD(Cornoldi et al., 2001), gambling (Andrade & Petry, 2012; Miedl, Peters, & Buchel, 2012; Petry & Casarella, 1999), drug addiction (Businelle, McVay, Kendzor, & Copeland, 2010; Meade, Lowen, MacLean, Key, & Lukas, 2011; Winstanley, Dalley, Theobald, & Robbins, 2004), alcohol consumption (Balodis, Potenza, & Olmstead, 2009) and smoking of marijuana (Johnson et al., 2010) or cigarettes (Reynolds, Richards, Horn, & Karraker, 2004). It has been suggested that impulsivity fits into a larger framework of negative health behaviours; where individuals are disproportionately focused on immediate gratification over the long term benefits of healthy habits (Hofmann, Friese, & Wiers, 2008).

Furthermore, measures of self-control, as characterized by the ability to delay gratification, have been found to be predictive of academic performance (Wulfert, Block, Santa Ana, Rodriguez, & Colsman, 2002), positive social relationships in adolescence (Mischel, Shoda, & Rodriguez, 1989),financial stability and income (Moffitt et al., 2011) and lower BMI in adulthood (Schlam, Wilson, Shoda, Mischel, & Ayduk, 2013).

It has been suggested that both probability and delay-discounting are reflections of the same fundamental trait (Green & Myerson, 1996) and this has led to descriptions of probability-discounting in terms of delay and *vice versa*. Delay-discounting can be defined in probability-

discounting terms in that as the delay before reward delivery increases, the probability of receipt decreases (Rachlin, Logue, Gibbon, & Frankel, 1986). Whereas, probability-discounting can be described using delay-discounting in that the lower the probability of the reward, the higher the number of attempts and, by association the more time, until reward acquisition (Rachlin, Siegel & Cross, 1994).

Others have asserted that, whilst the two processes interrelate, there are dissociable processes (Cardinal, 2006). One difference is what has been termed "the magnitude effect" in delay discounting (Christensen, Parker, Silberberg & Hursh, 1998; see Kirby, 1997 for a review) and "the peanut effect" in probability discounting (Weber & Chapman, 2005). The magnitude effect refers to the observation that small rewards are discounted more quickly than large rewards (Benzion, Amnon, & Yagil, 1989). For example, one might prefer €10 today to €20 in a week, suggesting that the delay of a week would need to be compensated by more than doubling the reward, but, if the delays were extended, prefer €20 in a 53 weeks to €10 in 52, showing that less than double the value of the reward is needed to compensate for the delay of a year. In probability-discounting individuals show more risk-seeking behaviour as the size of the reward decreases (Myerson & Green, 1995). For example, one might prefer a 50% chance of €2 to 100% chance of €1 but the definite option if both values are increased by a factor of 100 (50% chance of €200 or 100% chance of €100); i.e., they are willing to take a risk for 'peanuts'. By these descriptions it is possible to discern that, if risk-seeking equates to willingness to wait, the magnitude and peanuts effect are comparable; except they run in opposite directions (Weber & Chapman, 2005). This means that the overall value of the reinforcer may influence probability and delay-discounting differently (Green & Myerson, 2004; Green, Myerson, & Ostaszewski, 1999; Myerson, Green, Hanson, Holt, & Estle, 2003).

Animal behavioural models typically use food restricted subjects to facilitate responding, however, deprivation has been shown to enhance reward value (Heyman & Monaghan, 1987). Therefore, altering deprivation level can be thought of as having a similar effect to manipulating reinforcer magnitude (Ho, Wager, Bradshaw & Szabadi, 1997). Previous experiments examining the effect of devaluation of a food reinforcer on discounting rate have shown mixed results; with some studies reporting no effect (Cardinal & Howes, 2005; Cardinal, Robbins & Everitt, 2000) and others reporting a significant increase in impulsive responding in a probability task when subjects were satiated (St Onge & Floresco, 2009)

Delay- and probability-discounting are often described in terms of reward devaluation, i.e. the reduced likelihood of, or increased delay before reward receipt, lowers the reward's utility. This experiment aims to assess the impact of reward pre-exposure, i.e. devaluation, on the conditioned responses in a delay- and probability-discounting task. Yi, de la Piedad and Bickel (2006) previously observed a preference for delayed uncertain rewards over more immediate uncertain rewards, even when reward contingency was the same. One explanation given for this is that delayed rewards allow for "preparatory responses" such as anticipation (Rachlin et al., 2000 p. 156) and this phenomenon has been reported in both animals (Green & Rachlin, 1977) and humans (Loewenstein, 1987). Therefore, if anticipation or preparatory responding increases the value of the delayed reward and based on the findings of St Onge & Floresco (2009), we would expect the devaluation of the reinforcer to have more of an impact on responding for the large-probabilistic reward than the large-delayed reward. The current evidence would suggest that the responding in the delay-discounting procedure would be higher overall than that in probability-discounting. After devaluation, we would expect that responding would be higher in delay than in the probability-discounting procedure. This study aims to establish a reliable paradigm for the assessment of probability-discounting in mice; which, we believe at time of writing, would be the first example of this in the literature.

5.2: Experiment 5.1

5.3: Introduction:

Paradigms of discounting examine how changes to subjective cost, by lowering reward probability or increasing delay until receipt, leads to a preference reversal (Richards et al., 1997). The devaluation of reward utility has been studied in rodent models using a number of manipulations, including varying the delay before large-reward delivery (adjusting-delay; Mazur, 1987) and/or the size of the reward (adjusting-amount; Richards, Mitchell, DeWit & Seiden, 1997) based on previous selections, until the indifference point is reached. An alternative procedure involves the reward magnitudes remaining constant throughout but the subjective cost associated with the large-reward changing every block (Evenden & Ryan 1996). Typically, the associated cost starts at nothing (0 sec delay, 100% reward receipt) and then changes incrementally across blocks; for example, the large reward in the first block might be received after 0 seconds but by the final block be delayed by 60 seconds. In order to ensure that subjects experience the consequences of all the options, non-human animal models usually include forced trials wherein the trial does not end until the animal has selected the option presented and experienced the consequences of that

response. In addition to this, such procedures usually include a post reward inter-trial interval (ITI) in order to control for global, over local reward maximizing; i.e. subjects repeatedly selecting the small-reward to minimize delay and increase overall reinforcement (Blanchard, Pearson & Hayden, 2013). This methodology has been adapted for the examination of probability-discounting in rats (Simon, Gilbert, Mayse, Bizon & Setlow, 2009; Nasrallah, Yang, & Bernstein, 2009) although has not been extended to mouse models. The first aim of this experiment was to establish a model of probability-discounting using a mouse model.

5.4: Method

5.4.1: Subjects:

The subjects were 16 C57BL/6 mice housed in plastic and stainless steel cages in a climate controlled facility (temperature: *M*=21.58, max=21.8, min=21.2. Relative Humidity: *M*=46.84%, max=58%, min=35%) in pairs. Mice had an initial mean weight of 25.79 grams and were maintained on a 24 hour light/dark (12hr/12hr) cycle. The animals were food deprived throughout the study and were maintained at 90% of their initial body weight. Water was available *ad libitum* for the duration of the experiment. The procedures were conducted in accordance with the UK 1986 Animals (Scientific Procedures) Act 9 (project licence PPL 70/7072).

5.4.2: Apparatus:

The experiment was conducted in a set of conditioning chambers measuring 27 x 25.8 x 30.4 cm in length, width, and height respectively, were constructed from two metal and two clear acrylic walls. The active lever (w: 3cm, L: 1.76cm: 5.28cm²) was located (4cm) to the left of the sucrose magazine (counterbalanced to the right for half of the mice). The magazine (width= 1.8cm, height= 2.3cm, depth= 2.9cm) contained an infra-red beam that recorded the number and duration of head-entries. The 10% sucrose was coloured with 10 drops (per 500ml) of "*silver spoon*" green food colouring and delivered by 10ml plastic syringes mounted on syringe pumps (see *figure* 5.1).

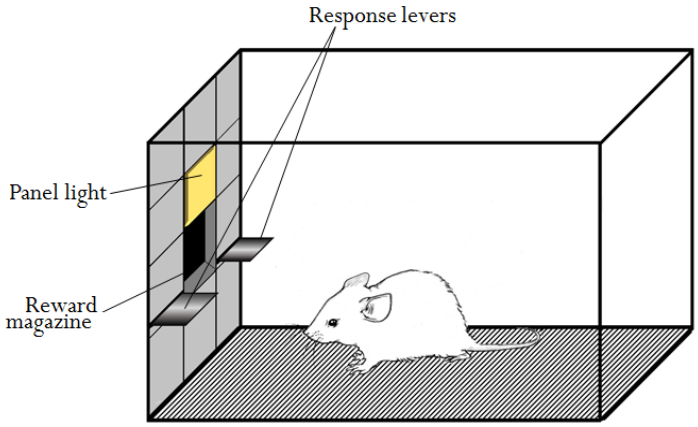


Figure 5.1: shows the arrangement of the operant chamber throughout all procedures. A computer running (MET-PC-IV) was interfaced with the chambers and recorded *lever presses (large reward and small reward), head entries into the magazine* and the times at which the behaviours occurred. All equipment was washed with fragrance-free soap and water between sessions and wiped with 70% ethanol between days.

5.4.3: Design:

This experiment examined the effect of subjective cost on reward choice. The dependent variables were proportion of large-uncertain reward lever presses to small-certain reward lever responses, and the proportion of large-delayed reward compared to the small-immediate reward lever presses. Initially (stage 4) the large reward was 55.0µl and the small reward was 18.4 µl of 10% sucrose but this was lowered during stage 6 to 41.33µl for the large-reward and 13.78µl for the small-reward. We also measured and *head entries* and *omissions* to the magazine.

The independent variables for probability-discounting were initially 0, 25, 50, 75 and 100%, before changing to 0, 33, 66, and 100%. For delay-discounting the levels were 0, 4, 8, 16 and 32 secs delay. Acquisition of the conditioned behaviour is shown by an increase in dependent variables across conditioning sessions.

5.4.4: Procedure:

In order to reduce expressions of neophobia, the mice undertook brief (twenty minutes for two days) magazine approach training before the experiment began. In this training, mice were placed in a conditioning chamber with a syringe pump activated on a RI30 schedule [min=15seconds, max=45seconds] set to deliver a small drop of sucrose solution [approximately 50µl] into the magazine (see *figure* 5.2.1).

Following magazine training animals undertook lever training for seven days. Lever training consisted of thirty minute sessions where animals received a 50 µl sucrose reward on completion of a lever response. Within sessions subjects were presented with single lever the location of which was kept constant within session but alternated between sessions (see *figure* 5.2.2).

Subjects then took part in magazine-lever training for six days. This consisted of five blocks of eighteen forced trials, wherein animals were presented with two levers, though never simultaneously. If the subjects completed a lever press within twenty seconds of lever insertion, they were issued a ~34µl sucrose reward; if no response was made, the lever was retracted. At this stage of training both levers produced the same quantity of reward (see *figure* 5.2.3)

Animals were then trained on a probability-discounting protocol, consisting of five blocks of twenty trials, for six days (see *figure* 5.2.4). On initiation of the session the panel light would turn on. This would then be followed by four forced trials (two small and two large-reward), as used in existing literature (e.g. Blanchard, Pearson & Hayden, 2013) wherein the options are presented independently, so individuals have the opportunity to experience the consequences of that response. For a forced trial either the large reward or small reward would be presented for 10 seconds; if a response was not made in this time, then lever presentation would be followed by a 20 second period wherein the lights of the chamber would be extinguished and neither lever would be presented. A lever press on the small-reward lever provided 18.4 µl sucrose reward, but a large-reward lever press produced 55.0µl sucrose reward. Following the forced trials, there were sixteen consecutive choice trials where both the small and large reward lever were presented simultaneously.

In block 1 the animal received both rewards with equal probability, 100%. As the blocks continued, the probability of small reward receipt remained 100% however, the likelihood of receiving the large reward reduced by 25% each block (block 2: 75%, block 3: 50%, Block 4: 25% Block 5: 0%). The four forced trials (two per lever) served to delineate the initiation of each block and ensure that subjects experienced the outcome of the small and large reward
After completion of this initial probability-discounting training animals were returned to magazine-lever training for six more days, the protocol for which had not changed (see *figure* 5.2.5).

Animals then resumed probability-discounting for two days, with some procedural adjustments. The large reward contingencies and reward amount were reduced as animals were found to be satiating during training. The small reward was then reduced to 13.78µl and the large reward was changed to 41.33µl and the large-reward contingencies were lowered to 0, 33, 66, and 100%. With the new probabilities, the structure of the blocks was changed, the sessions now consisted of twenty-two trials per block. The initiation of each new block was signalled by twelve forced trials to improve probability learning, as described before, followed by ten choice trials (see *figure 5.2.6*).

Subjects were trained on a delay and probability-discounting protocols, in parallel. Subjects would complete one discounting program in the morning and the other in the afternoon, with program order was counterbalanced across individuals. Throughout delay-discounting training, the quantities for the small and large reward remained the same as they had been during probability-discounting. The delay-discounting protocol consisted of five blocks of twelve trials. As with probability-discounting, the initiation of a new block was signalled by forced trials, in this case four, followed by eight choice trials. The probability of reward receipt remained at 100%; however, the delay large-reward receipt increased with each consecutive block from 0, 4, 8, 16 and 32 sec but remained immediate (0 sec) for the small-reward (see *figure 5.2.7*).

The dependent measures included the average number and duration of head entries, and the proportions of large over small-reward choices per block (either probability or delay).

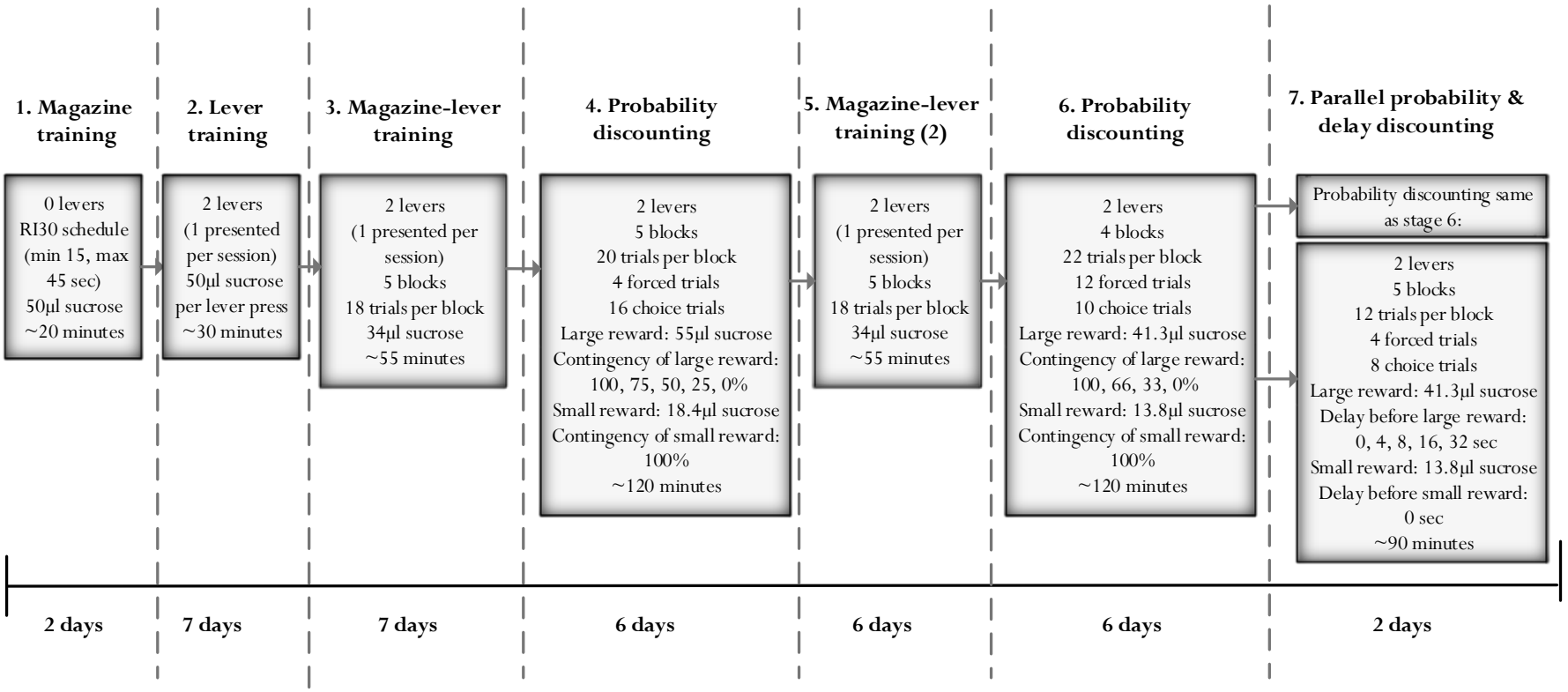


Figure 5.2: shows the stages of the experimental procedure

5.5: Results:

The stages of the procedure relevant for the examination of probability and delay-discounting are four, six and seven (see *figure* 5.2) and are analysed below.

5.5.1: Stage four: probability-discounting training: large reward contingencies: 0, 25, 50, 75, 100%:

There was a significant effect of *block* on the average proportion of large-reward lever choices, $F(4, 60) = 32.48$, $p < .001$, partial $\eta^2 = .68$ (see *figure* 5.3). Simple comparison post hoc tests revealed subjects made significantly more large-reward choices when the contingency was 100% than all other contingency blocks (*ps*<.001). This result shows subjects were reliably distinguishing between the different reward probability blocks.

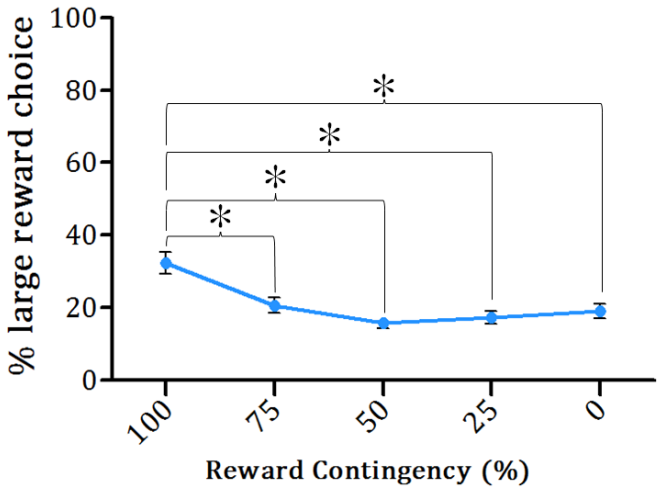


Figure 5.3: proportion of responses directed at the large-reward lever per block during initial probability discount training (0, 25, 50, 75, and 100%) (Error bars ±SE; asterisks denote significant differences)

5.5.2: Stage six: probability-discounting training: large reward contingencies: 0, 33, 66, 100%:

As previously, there was a significant effect of *block* on large-reward choice, $F(3, 45) = 53.43$, $p < .001$, partial $\eta^2 = .78$. Bonferroni corrected post-hocs showed the number of lever presses made when the large reward contingency was 100% was significantly higher than all other contingency blocks (*ps*<.001) (see *figure* 5.4).

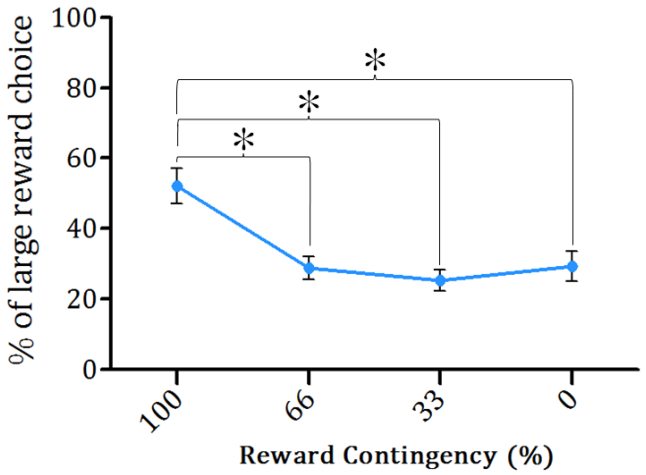


Figure 5.4: proportion of responses directed at the large-reward per block during probability discount training (0, 33, 66, and 100%) (Error bars ±SE; asterisks denote significant differences)

5.5.3: Stage seven: simultaneous probability- and delay-discounting training

5.5.3.1: Delay-discounting analysis:

There was a significant effect of *block* on large-reward choice, F (4, 60) =46.02, p<.001, partial η^2 =.75 (see *figure* 5.5). Further analysis showed that subjects made significantly more large-reward lever presses during the 0 sec delay than all other delay blocks, apart from 4 sec (*ps*<.001).

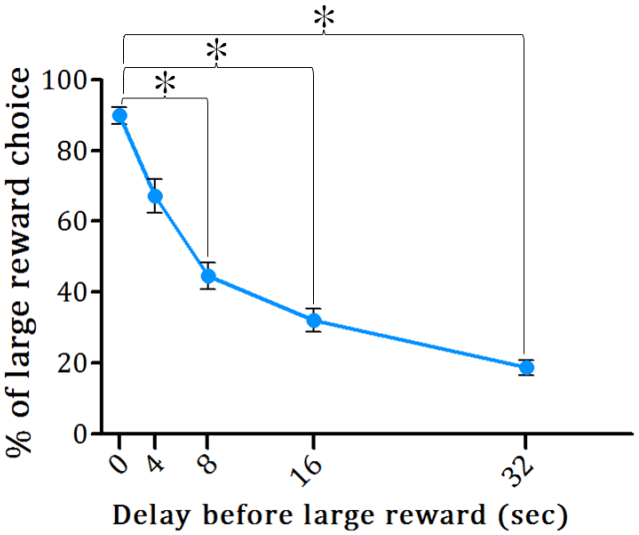


Figure 5.5: proportion of responses directed at the large-reward per block during simultaneous probability and delay discount training (0, 4, 8, 16, and 32 sec delay (error bars ±SE; asterisks denote significant differences)

5.5.3.2: Probability-discounting analysis:

There was a significant effect of *block* on large-reward choice, $F(3, 45) = 18.37$, $p < .001$, partial $\eta^2 = .56$ (see *figure* 5.6). Bonferroni post hoc tests revealed a significant difference in the average number of lever presses performed in the 100% than 66% ($p = .003$), 33 and 0% blocks ($ps < .001$).

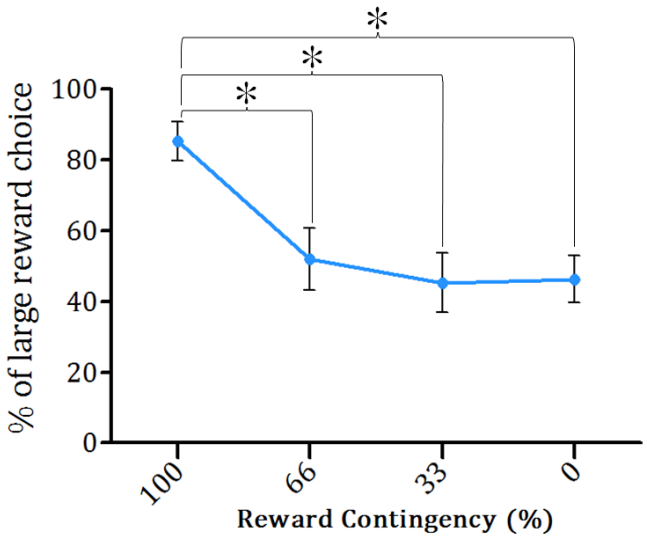


Figure 5.6: proportion of responses directed at the large-reward per block during simultaneous probability and delay discount training (0, 33, 66, and 100% Probability) (error bars ±SE; asterisks denote significant differences)

A four (block: 100, 66, 33 and 0) by two (stage: probability-discounting alone vs. probability and delay-discounting simultaneously) repeated measures ANOVA was conducted to assess whether probability-discounting behaviour had changed as a result of simultaneous delay-discounting training. Results revealed a significant effect of stage, $F(4, 60) = 46.02$, $p < .001$, partial $\eta^2 = .75$; analysis of the means shows that large reward choice was significantly higher, overall, when subjects were taking part in simultaneous probability and delay-discounting

5.6: Discussion:

One of the fundamental aims of this experiment was to establish whether the protocol of probability-discounting could be adapted to a mouse model, the results from stages four, six and seven (see *figure* 5.2) consistently show that animals are able to distinguish between different probabilities when selecting a reward. The results of probability-discounting (stages four and six) showed that animals would consistently select the large-reward lever, when the reward contingency was high; however, as the blocks continued, and the probability of receiving the large

reward dropped, they would switch to the small-certain reward. Our manipulations show that the mice could identify differences in contingency at two increments: 25% and 33% drops in probability. The results from stage seven shows that the animals also reliably discounted delayed rewards, in accordance with earlier findings (Oberlin &Grahame, 2009). The initiation simultaneous probability and delay-discounting training resulted in a significant increase in responding during probability-discounting trials.

5.7: Experiment 5.2

The second aim of these experiments was to examine how discounting behaviour was affected by satiety-induced devaluation before initiation of discounting. In order to assess this, subjects were pre-exposed to the discounting reinforcer (10% sucrose) or a control reinforcer (reduced fat milk). If prior exposure to the reinforcer is sufficient to devalue it, in an outcome specific manner, we would expect preference reversal to occur more rapidly after initiation of the task in the subjects pre-exposed to sucrose to the than those pre-exposed to milk.

In addition, research conducted in humans has shown that the order in which delays are presented (increasing or decreasing) can influence how rapidly participants reach a preference reversal (Robles et al., 2008; 2009). For this reason, the experiment aimed to assess whether presenting the delay blocks in the reverse order influences discounting of the large sucrose reward.

5.8: Method:

Subjects and apparatus are the same as in experiment 5.1.

5.8.1: Design:

As in experiment 5.1, the dependent variables were the proportion of large reward lever choices. The independent variables were the reward the animals were pre-exposed to during devaluation either milk (*maintained*) or sucrose (*devalued*) and the large reward contingencies, initially 0, 25, 50, 75 and 100%, before changing to 0, 33, 66, 100%.

5.8.2: Procedure:

Animals were pre-exposed to either fat-free milk or 10% sucrose in their home cages for 2 hours prior to testing (counterbalanced across days). Animals and bottles were weighed before and after exposure. Following this animals completed the probability and delay-discounting procedure as before. Devaluation took place over 4 days. In order to assess the effectiveness of the devaluation

manipulation, large and small reward choices were compared to the response rates on the day prior to devaluation, this value is referred to as “baseline”.

During experiment 5.1, both probability and delay-discounting training had always consisted of the animal receiving the most reward at the beginning of the session and then this gradually declining; for this reason, the devaluation procedure was repeated with the block order reversed.

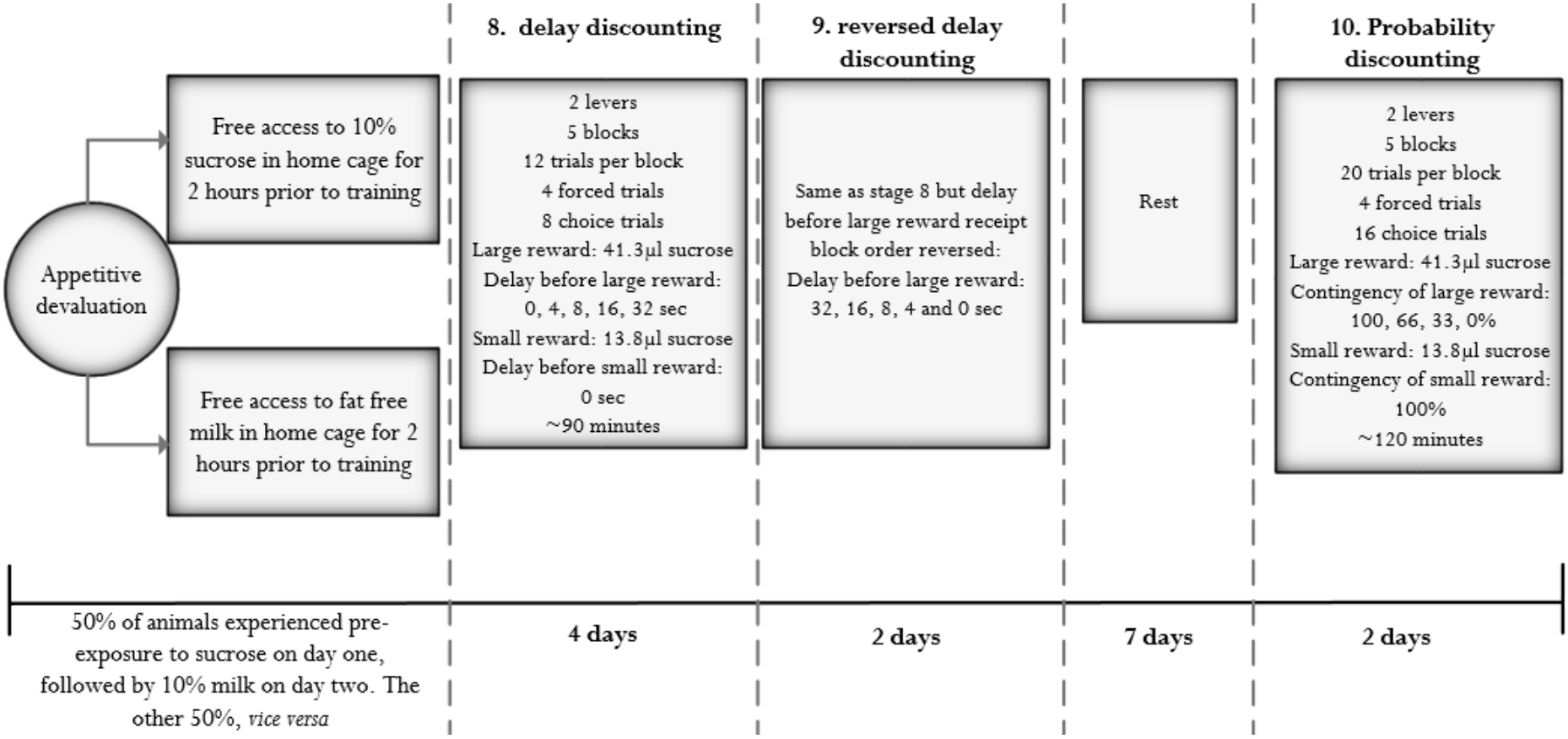


Figure 5.7: shows the stages of the experimental procedure

5.9: Results:

5.9.1: The effect of pre-treatment:

The average intake volume of milk (*M*=11.92, *SE*=0.56) or sucrose (*M*=12.04, *SE*=0.52) before and after pre-exposure was not significantly different, t (7) =-.199, p=.848. The average weight gain in the maintained (*M*=0.88, *SE*=0.48) and sucrose devalued (*M*=0.87, *SE*=0.57) conditions before and after devaluation was not significantly different, t (15) =.116, p=.909. These results suggest that one pre-treatment group did not consume markedly more reward than the other.

5.9.2: Stage 8: devalued delay-discounting analysis:

A three (pre-exposure treatment: baseline, devalued, maintained) by five (block: 0, 4, 8, 16 and 32 sec) repeated measures ANOVA was used to assess the selection of the large reward. There was a significant effect of *block* on large-reward choice, F (4, 60) =85.90, p<.001, partial η^2=.85. Simple comparison post hoc tests revealed a significant difference in the average number of lever presses performed in the 0 and 4 sec delay blocks (p=.001) and 0 sec all other delay blocks (*ps*<.001) .

The effect of pre-exposure treatment on large reward was approaching significance, F (4.40, 66.02) =2.41, p=.053, partial η^2=.14. As shown by *figure* 5.8, after consumption of the sucrose reward, subjects tended to select the large reward less often than they had at baseline, or after being pre-exposed to milk, but these differences were not statistically significantly.

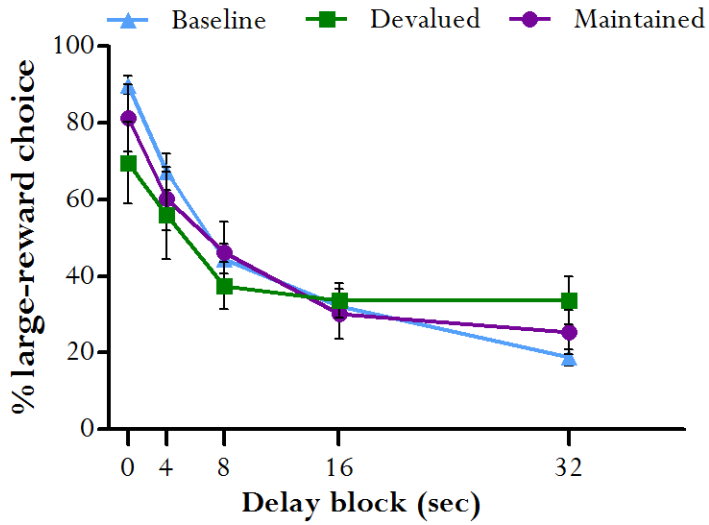


Figure 5.8: proportion of responses directed at the large-reward per block compared to baseline (same data as figure 5.5) during maintained and devalued delay-discounting test (0, 4, 8, 16, and 32 sec) (error bars ±SE)

5.9.3: Stage 9: reverse block presentation devalued delay-discounting:

A two (order: ascending delay, descending delay) by five (block: 0, 4, 8, 16 and 32 sec) repeated measures ANOVA was conducted on percentage of large lever presses. There was a main effect of order, F (1, 15) =4.96, p=.042, partial η^2=.25, analysis of the means revealed that subjects selected the large lever significantly more when the blocks were presented in an ascending (M=46.29, SE=3.38) than descending order (M=34.92, SE=5.44).

There was a significant effect of block, F (4, 60) =8.93, p<.001, partial η^2=.37. Subjects selected the large reward significantly more in the 0sec delay block (M=49.22, SE=4.55) than the 4sec (M=39.94, SE=4.39, p=.005), 8sec (M=35.35, SE=4.77, p=.005) and 16 sec delay block (M=35.25, SE=3.86, p<.001). There was no significant difference between the 0sec and 32sec delay blocks (M=43.26, SE=2.78).

There was a significant interaction between order and reward size, F (4, 60) =38.21, p<.001, partial η^2=.72. When delays are presented in an ascending order subjects selected the large reward significantly more in the 0sec than the 4 sec delay block (p=.009) and significantly more than during the 8, 16 and 32 sec blocks (p<.001) (see *figure* 5.9). However, when delays were presented in descending order the large reward was selected significantly in more in the 32 sec than the 0 and 4 sec (p=.001), 8 sec (p=.013) and 16 sec delay blocks (p=.009) (see *figure* 5.9).

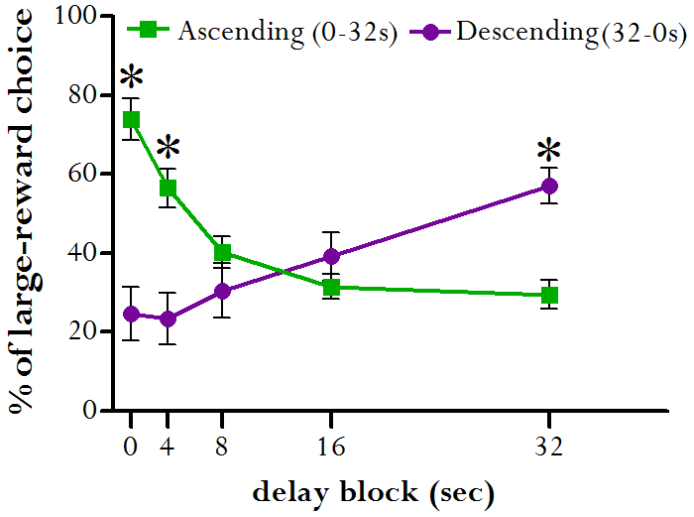


Figure 5.9: proportion of responses directed at the large-reward per block when delay blocks are presented in an ascending (0, 4, 8, 16, and 32 sec) or descending (32, 16, 8, 4 and 0sec) order. (Error bars ±SE; asterisks denote significant differences between presentation orders)

A two (pre-exposure treatment: milk, sucrose) by (order: ascending delay, descending delay) by five (block: 0, 4, 8, 16 and 32 sec) 3 way repeated measures ANOVA was then used to assess whether pre-exposure condition differentially+ effected discounting on the ascending or descending order; there was no significant difference, $F(4, 60) = 0.74$, $p = .568$ (*Figure* 5.10)

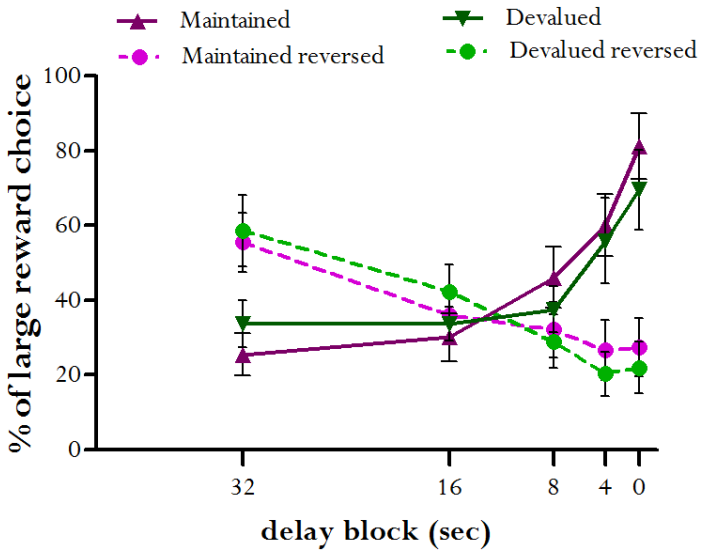


Figure 5.10: proportion of responses directed at the large-reward per block during reverse block devalued delay-discounting test (32, 6, 8, 4, and 0 sec delay) (error bars ±SE)

5.9.4: Stage 10: devalued probability-discounting analysis:

A two way ANOVA was then used to compare large-reward choice cross blocks and pre-exposure treatments. There was a significant effect of *block* on large-reward choice, $F(3, 45) = 17.85$, $p < .001$, partial $\eta^2 = .54$. Simple comparison post hoc tests revealed the average number of lever presses performed in 100% ($M = 8.65$, $SE = 0.66$) contingency block was significantly higher than the 66 ($M = 5.79$, $SE = 0.69$, $p = .001$), 33% ($M = 5.88$, $SE = 0.65$, $p = .002$) and 0% blocks ($M = 5.50$, $SE = 0.66$, $p < .001$). There was no significant effect of pre-exposure treatment alone, $F(2, 30) = 4.84$, $p = .621$. There was, however, a significant pre-exposure treatment by block interaction, $F(6, 90) = 2.76$, $p = .017$, partial $\eta^2 = .16$ (see *figure* 5.11). Further analysis revealed that compared to baseline ($M = 10.25$, $SE = 2.95$), when subjects were pre-exposed to milk there was no significant change in the large reward selection ($M = 8.31$, $SE = 4.08$); however, subjects picked the large reward significantly less when pre-exposed with sucrose ($M = 7.38$, $SE = 4.08$, $t(15) = 2.64$, $p = .018$)

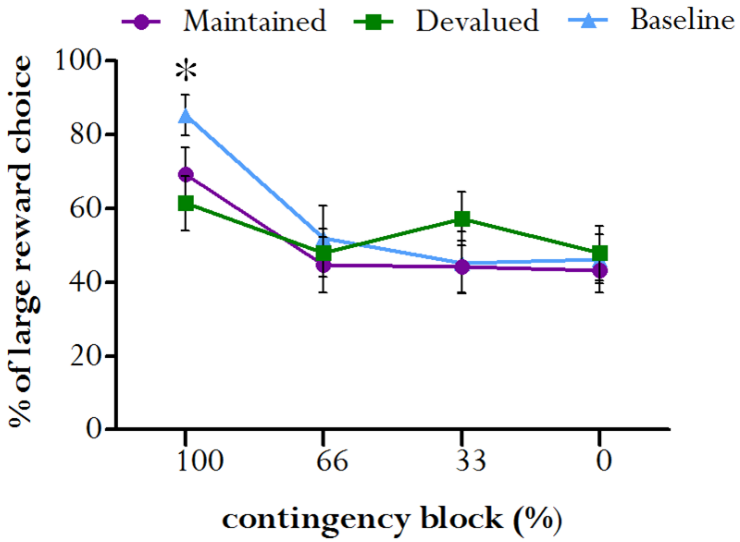


Figure 5.11: proportion of responses directed at the large-reward per block during *devalued* probability-discounting test compared to baseline (0, 33, 66, and 100% Probability) (error bars ±SE)

5.10: General discussion

These experiments aimed to establish a mouse model of probability-discounting, homologous to those previously utilised in rats. The paradigms used here established probability-discounting at two incremental changes per block, 25 and 33% and at the time of writing, appears to be one of the first to do so. Experiment 5.2 set out to examine two factors; firstly, what effect reward pre-exposure had on discounting and secondly, whether presentation order effected delay-discounting.

Results showed that the devaluation of the reinforcer by pre-exposure, and possible satiation, had a significant effect on large-reward choice over small-reward choice for the probability, but not the delay-discounting paradigm. A possible explanation for this is that if the delay before the reward extends its experienced utility though anticipation (Loewenstein, 1987), that the value of the reward in the delay-discounting program is higher than in the probability-discounting protocol. If so, anticipation rendered the delayed reinforcer robust against satiety, but probability-discounting was unaffected. Further to this, in experiment 5.1 subjects were first trained on probability-discounting alone (stage 6) and then probability and delay-discounting simultaneously (stage 7), between stages 6 and 7 there was a significant increase in responding on the probability-discounting program. Considering the results of experiment 5.2, it is possible that this is due to an increase remembered or predicted utility of the reward, caused by anticipation in

the delay-discounting paradigm. The contrasting effect of pre-exposure to the reward on probability and delay-discounting behaviour lends support to the assertion that, rather than representing aspects of the same fundamental trait (Green & Myerson, 1996), the devaluation of probabilistic and delayed rewards are associated but distinct processes (Cardinal, 2006).

There is evidence from imaging studies suggesting that the mechanistic underpinnings of probability and delay-discounting are disparate (Peters & Buchel, 2009). In support of, Shizgal's (1997) description of utility as the common currency of the brain, subjective value, irrespective of whether it is probabilistic or delayed appears to be coded by the ventral striatum and orbitofrontal cortex (Peters & Buchel, 2009; Christopoulos, Tobler, Bossaerts, Dolan, & Schultz, 2009; Miedl, Peters & Buchel, 2012). Conversely, evidence has been found of risk being signalled by the dorsal anterior cingulate (Christopoulos et al., 2009) and superior parietal cortex and middle occipital regions (Peters & Buchel, 2009). Whereas delay has been associated with activity in the frontopolar and lateral parietal cortex (Peters & Buchel, 2009).

Another rationale is the amount effect; meaning that the size of the reward has the opposite effect on probabilistic and delayed discounting rates: large rewards were discounted at the same or slightly faster rate than small rewards, conversely, large delayed rewards are discounted more slowly than small rewards (Green, Myerson, & Ostaszewski, 1999).
This investigation also sought to assess the influence of presentation order on discounting behaviour. It was hypothesised that, in accordance with previous research with humans, the descending-delay presentation order produced more "impulsive" responding than an ascending sequence (Robles & Vargas, 2008; Robles et al., 2009; Fox, Hand, & Reilly, 2008). Comparison of response rates on the ascending and descending sequence revealed that, irrespective of presentation order, subjects selected the large reward most in the first block, suggesting the results from this experiment are confounded by order effects. A possible explanation for this is that the training that the subjects experienced prior to presentation of reversed delay sequence had made the responding more habitual. The presentation of the reversed delay sequence took place across two sessions on consecutive days. In order to reduce such effects in future, it would be beneficial to have a more substantial break between the training sessions for each presentation order, balance the number of exposures to each presentation order or use a discrete cue to indicate presentation order.

Overall, these experiments have shown that delay and probability-discounting are observable in mice. According to the results of this investigation it appears, however, that delay-discounting behaviour is more robust to the effects of devaluation than probability-discounting.

Chapter 5: probability- and delay-discounting in mice

- Mice acquired delay-discounting behaviour and probability-discounting at two increments (25 and 33%)
- Devaluation of sucrose rewards effected probability but not delay-discounting
- After initial training of probability-discounting alone, initiation of simultaneous delay-discounting training potentiated the established probability-discounting responding.
- When delays were presented in a descending order behaviour showed evidence of order effects.

6. The effect of devaluation on an implicit experiential delay- and probability-discounting task in humans

Abstract:

Devaluation of rewards can occur due to increases in subjective cost by delaying, or reducing the probability of, reward receipt. This series of experiments examines the effect of block presentation order on discounting behaviour, devaluation by pre-exposure and priming on probability-discounting using a novel, implicit computerized task. In addition, the influences of trait impulsivity, alcohol use and drug-use on choice behaviour were explored. Results showed the devaluation manipulation acted as a prime and this effect was potentiated in the overly controlled participants for delay-discounting and highly impulsive participants for probability-discounting. There was no relation between alcohol consumption and discounting behaviour

Keywords: probability and delay-discounting, devaluation, prime, presentation order, trait impulsivity, state impulsivity, BIS-11

When presented with a choice, an individual will use their previous experience to assess the subjective cost and potential reward of each option. Even treasured reinforcers can, subjectively at least, lose their value as a function of external factors. This phenomenon is known as 'discounting', with temporal discounting referring specifically to the mechanism by which rewards lose value, or utility, over time and probability-discounting pertaining to how utility changes as a function of receipt contingency (MacKillop, 2013).

The effect of this subjective devaluation can be measured using choice paradigms; participants are asked to choose between a small, certain reward and a larger variable reward, the likelihood or delay until receiving the reward is systematically varied across a number of trials. These incremental changes aim to decrease the large reward utility by increasing the subjective cost, leading to an *indifference point*, wherein the present value of the large variable reward and small constant reward is equivalent, and subsequently *preference reversal* (Richards, Mitchell, De Wit, & Seiden, 1997). Due to the enduring nature of discounting rates, discounting assessments have been shown to be reliable up to a year later (Smits, Stein, Johnson, Odum, & Madden, 2013),

Odum (2011) suggested that the degree of discounting reflects a personality trait. It has been argued that discounting reflects impulsiveness (MacKillop et al., 2011); those who are able to relinquish more immediate but less satisfying rewards, in preference for delayed substantial rewards, are said to be "self-controlled"(Rachlin, Brown, & Cross, 2000). According to this view, impulsive responding in probability-discounting is a preoccupation with potential reward size rather than the likelihood of its receipt (Shead & Hodgins, 2009). Whereas, for delay-discounting, impulsive people are delay averse, meaning they discount delayed rewards more rapidly than controls (see Perry & Carroll, 2008 for review). However, if one's willingness to wait for a reward corresponds to how risk seeking one is (Weber & Chapman, 2005; Yi, de la Piedad & Bickel, 2006), then it is possible to discern that reward size has the opposite effect on risk-seeking behaviour in probability- and delay-discounting. The tendency to be more risk-adverse for large rewards in delay discounting is known as the "magnitude effect" (Christensen, Parker, Silberberg & Hursh, 1998; see Kirby, 1997 for a review) and the propensity to show more risk-seeking behaviour as the size of the reward decreases in probability-discounting is termed the "peanuts effect" (Myerson & Green, 1995). For example, in delay-discounting a one might prefer the risk adverse €10 today to €20 in a week but, if an equal delay were added to both options, e.g. €10 in 52 weeks or €20 in 53 weeks, preference tends to switch to the delayed alternative. Conversely, in probability-discounting, one might opt for the risky option when the rewards are small, e.g. 50% chance of €2 or 100% chance of €1, but if the magnitude of the reward is increased by a factor of 100, 50% chance of €200 or 100% chance of €100 prefer the definite, non-risky option. Compared to delay-discounting, research into probability discounting is quite limited; a possible reason for this is that discounting for probabilistic or delayed rewards are thought to represent the same underlying process (Green & Myerson, 1996) or, alternatively, because probability-discounting is included in measures of risk or sensation seeking.

Some have suggested that the high levels of relapse seen in drug addicts after cessation is due to an insensitivity to delayed consequences, as so many substance abusers seek treatment only to relapse a few weeks later (McKay, Franklin, Patapis, & Lynch, 2006); explained in discounting terms, when the value of their craved drug exceeds the value of their long-term goal for abstinence. This proposition is supported by evidence that, compared to controls, drug and alcohol abusers exhibit a preoccupation with present, compared to past or future, events (Stein & Madden, 2013). Using the well-established Barratt Impulsivity scale (BIS), de Wit et al. (2007) found a positive correlation between levels of non-planning and delay-discounting rate, and proposed the explanation for this is that both discounting and the non-planning BIS subscale assess one's relative

sensitivity to delayed consequences. Further to this, substance abusers typically discount delayed rewards more rapidly than matched controls (Kirby, Petry & Bickel, 1999; Petry & Casarella, 1999; Heil, Johnson, Higgins & Bickel, 2006) though this has not been reliably reproduced using probability-discounting (Andrade & Petry, 2012).

Alternatively, impulsive "maladaptive" decisions might be the result of an over-estimation of elapsed time, leading to heightened sensitivity to reward (Martin & Potts, 2009) and more rapid discounting of delayed rewards (Baumann & Odum, 2012); i.e. an impulsive individual may perceive the delay before the large reward as longer than a self-controlled individual and, as a result, be more likely to select the small immediate reward. Another explanation is that our desire for an immediate reward is innate and that the discounting of rewards reflects an under-utilized or, in the case of clinical populations potentially insufficient, self-regulatory process (Baumeister & Heatherton, 1996; Hofmann, Friese, & Roefs, 2009) or action restraint process (Dalley, Everitt, & Robbins, 2011) . In support of this, Reynolds, Leraas, Collins and Melanko (2009) found that the children of smokers discounted significantly faster than the children of non-smokers. Whilst it is not clear as to whether this result is due to genetic or common environmental factors, high rates of delay-discounting may increase the likelihood of an individual initially experimenting with drugs or cigarettes (Bickel, Jarmolowicz, Mueller, Koffarnus, & Gatchalian, 2012).This association between drug use and discounting behaviour has led to increased interest in discounting procedures (Bickel, MacKillop, Madden, Odum & Yi, 2015) but particularly in non-human animal models, which can inimitably explore the effects of acute and chronic drug exposure (de Wit & Mitchell, 2010) and underpinnings of such behaviours (Odum & Baumann, 2010). For this reason, it is extremely important to establish analogous protocols of discounting for human and non-human empirical research wherever possible.

The measurement of such choice valuation in humans can be done using self-report questionnaires (Kirby & Maraković, 1996; Kirby et al., 1999) or behavioural tasks (Dougherty, Marsh, & Mathias, 2002) and this has been done using a wide variety of rewards including non-monetary tokens (Reed & Martens, 2011), hypothetical (Weatherly & Ferraro, 2011) and real money (Hofmeyr, Ainslie, Charlton, & Ross, 2011) and hypothetical drug rewards (Madden, Bickel, & Jacobs, 1999)

The most commonly used self-report delay-discounting measure is Kirby, Petry, and Bickel's (1999) 27-item questionnaire (based on the Kirby & Maraković, 1996) which is an example of a 'monetary price list', wherein participants need to choose between 2 items and their relative

delays e.g. "*Would you prefer £35 today or £49 in 23 days?*". Research by Lagorio and Madden (2005) has demonstrated this methodology to be consistent across multiple test sessions, indicating that the degree of discounting is not being affected by multiple exposures; rather, changes in discounting rate are likely the result of increased deprivation (e.g. financially or economic inflation).

Item order in such questionnaires has been shown to significantly affect discounting rate (Robles & Vargas, 2007; 2008; Robles, Vargas & Bejarano, 2009). Robles et al. presented a range of 30 reward values at 8 delays in an ascending, descending or random sequence. The initial investigation suggested that a random sequence produces the most rapid discounting rate and this was attributed to having to repeatedly adjust to a new sequence and reward size, increasing task difficultly (Robles & Vargas, 2007). However, later investigations showed a significantly faster discounting rate when an ascending order was used rather than either a descending or random (Robles & Vargas, 2008; Robles, Vargas & Bejarano, 2009). This may be due to a perceived worsening or improving of sequences or participants comparing current reward and delay options with those presented on previous trials (Lockhead, 2004). Discounting rate can also be manipulated to be significantly steeper by priming participants to be aware of the duration of the task (Zauberman, Kim, Malkoc & Bettman, 2009).

Discounting can also be assessed behaviourally in humans using the Experiential Discounting Task (EDT) (Reynolds & Schiffbauer, 2004). Unlike other forms of assessment (Bickel, Odum, & Madden, 1999; Cano Cervantes, Araque Serrano, & Candido Ortiz, 2011), in this paradigm participants experience trial-by-trial consequences for their decisions (Reynolds, Richards, & de Wit, 2006); which has led to the suggestion that the EDT will be more sensitive to factors such as delay aversion than hypothetical question-based discounting tasks (Reynolds et al., 2006).

The most commonly utilised model of discounting in non-human animals is the Evenden and Ryan (1996) procedure. These tasks are split into blocks and subjects choose between small reward, which is delivered immediately throughout the protocol, and a large reward, the delay before which gradually increases as the blocks continue. Subjects learn the reward size and associated delay by completing forced trials at the beginning of each block. The EDT also includes forced trials; however, unlike animal experiments, these forced trials are contingent on previous responding. In order to equalise trial length, Evenden and Ryan (1996) discounting experiments typically include a post-reward ITI, however this is also absent from the EDT. This means that the selection of the supposedly "maladaptive and impulsive" small option would allow for greater

local and overall rate-maximization (Logue, Peña-Correal, Rodriguez, & Kabela, 1986). In order to ensure that the current models are as similar as possible to animal models, that participants are not completing more trials, omitting or merely picking the small reward so as to end the procedure as quickly as possible, the paradigm length needs to be controlled by inter-block intervals calculated based on previous choices as in non-human animal procedures; which is absent from the EDT.

Another major way that the EDT differs from traditional and non-human animal delay-discounting assessments is that the receipt of the large reward in EDT is both delayed and probabilistic (the chance of receiving cash 35% across all blocks). This additional probabilistic component to the EDT might explain why it has not been found to correlate with traditional delay-discounting measures (Peters, Petry, LaPaglia, Reynolds, & Carroll, 2013). Anderson and Stafford (2009) showed that very few participants were consistently risk averse in the presence of risk and delay together and, rather, that increased risk led to accelerated discounting. Furthermore, not only has the addition of a probabilistic component into a delay-discounting measure been demonstrated to significantly affect discounting rate (Weatherly, Petros, Jónsdóttir, Derenne & Miller 2014); but, Smits et al. (2013) discovered that participants were utilising the probabilistic component of the EDT to drive up their reward, by selecting the large reward in order to increase the value of the small reward. Therefore, this element of risk, of which the participants are aware may lead to a miscalculation of discounting rate.

Early research into delay-discounting in humans indicated that adult humans can exhibit strong self-control in decision making studies when the reward they stand to win is points (Logue, King, Chavarro, & Volpe, 1990). Later, research by Hyten, Madden and Field (1994) indicated that participants could be indifferent towards points as an outcome; however, they identified that by including an animation of points counting up would increase the salience of the reward and demonstrate more clearly the disparity between the small immediate (certain) choice and the larger, delayed (probabilistic) reward choices.

This experiment represents the first protocol for a computerized delay and probability-discounting procedure which is controlled for task duration. The *Sussex delay-/probability-discounting computer tasks* (SDDCT/SPDCT respectively) were closely based on probability- and delay-discounting paradigms using animal models. Critical features of these tasks include, the fact they are implicit (i.e. neither rewards nor subjective costs are cued), task duration is controlled by inter-block interval and, in the SDDCT, both large and small rewards have a 100%

probability. For this reason, it is necessary to examine the effect of block order on both delay- and probability-procedures to assess the duration of the task, the number of trials and the effectiveness of points as a reinforcer.

In order for the SDDCT and SPDCT to be as translatable as possible across species, parameters were kept at the same level as they were in our previous mouse model. Our protocol differed from the established EDT in several important ways, firstly, the delay before reward receipt was explicitly cued. Secondly, values of the options are not stated rather, participants completed forced trials at the beginning of each block, as in animal studies, so the outcome of the choices were learned through experience rather than read. Thirdly, the delay and probability parameters were examined individually in separate protocols rather than in conjunction as in the EDT. It has previously been demonstrated that a global evaluation of a remembered episode is based on the weighted average of the most intense part (the peak) and the finale (the end) of the experience (Kahneman, Fredrickson, Schreiber & Redelmeier, 1993). As the presentation of the programs needed to be counter-balanced, perception of elapsed time was compared across conditions to examine whether where the delay-discounting program was completed in sequence led to over-estimation of task duration. In addition, we aimed to examine the effect priming and devaluation on discounting behaviour and whether these effect differ across behavioural classifications. We expect that those classified as impulsive by the BIS, binge drinkers and drug users will discount more rapidly than their counterparts.

6.2: Experiment 6.1:

6.3: Method

6.3.1: Participants:

13 participants were recruited (see general methods), their mean age was 22.6 years of age (*SE*=0.80). There were 12 females.

6.3.2: Materials:

The materials for the study were three *e-prime* programs, with the same parameters as used previously in our mouse model, but with the blocks presented in three different orders: random, ascending and descending. These titles refer to the subjective cost associated with the large reward. In the random program, the blocks (100%, 66%, 33% and 0%) and blocks (0, 4, 8, 16 and 32sec) were presented non-sequentially. In the descending program, as the blocks continue, the likelihood of receiving the reward increased and the delay decreased across blocks- decreasing

subjective cost associated with the large reward (see *table 6.*1); for the ascending program, block presentation is reversed. The design of this experiment was a two (training order: probability or delay-discounting program first) by three (block presentation: ascending, descending random) mixed measures design. Responses were collected using a serial response box, with the buttons marked with arrows to match the stimuli in the task.

	Order name	Sequence
Probability-discounting	*Ascending*	100, 66, 33, 0
	Descending	0, 33, 66, 100
	Random	Non-sequential
Delay-discounting	*Ascending*	0, 4, 8, 16, 32 sec
	Descending	32, 16, 8, 4, 0 sec
	Random	Non-sequential

Table 6.1: shows the order in which the large, reward choice varied across blocks for the three programs used in the experiment 6.1 study

6.3.3: Procedure:

Participants were allocated to one of three block presentation conditions: ascending, descending or random first. All participants completed all three of the delay and probability-discounting procedures (six programs in total: training order was counterbalanced). Participants were also allocated to a training-order condition: depending on whether the participant completed the three probability programs before or after the three delay programs.

The participants were told that the aim of the games was to win as many points as possible. In all programs, at the beginning of each block, participants completed a number of forced trials so they could learn the CS-CR contingencies/delays; participants were presented with a single arrow, pointing either left or right (*figure 6.*1b or 4.1e) and were asked to indicate which side of the screen the arrow had appeared, using the Serial Response Box (SRB). One arrow represented the small-reward, meaning if participants responded correctly they would win 5 points. The other arrow represented the large-reward, associated with 15 points (counterbalanced across participants; in *figure* 6.1, left represents the small and right the large reward). This task is referred to as *implicit* as participants are never expressly told the reward or subjective cost associated with either response, and instead must learn them through experience during the forced trials. If participants responded with the opposite arrow (i.e. incorrectly), or made no response they received zero points. On completion of the forced trials, participants were given

choice trials (*figure 6.*1h) wherein two arrows were presented so participants could choose either direction, based on their previous experience of points and associated penalty.

The probability-discounting program was 4 blocks of 32 trials each (10 forced and 22 choice). In each block the probability of receiving the large reward (15 points) was varied (100, 66, 33 and 0%), but receipt of the small reward (5 points) remained certain (100%) throughout.

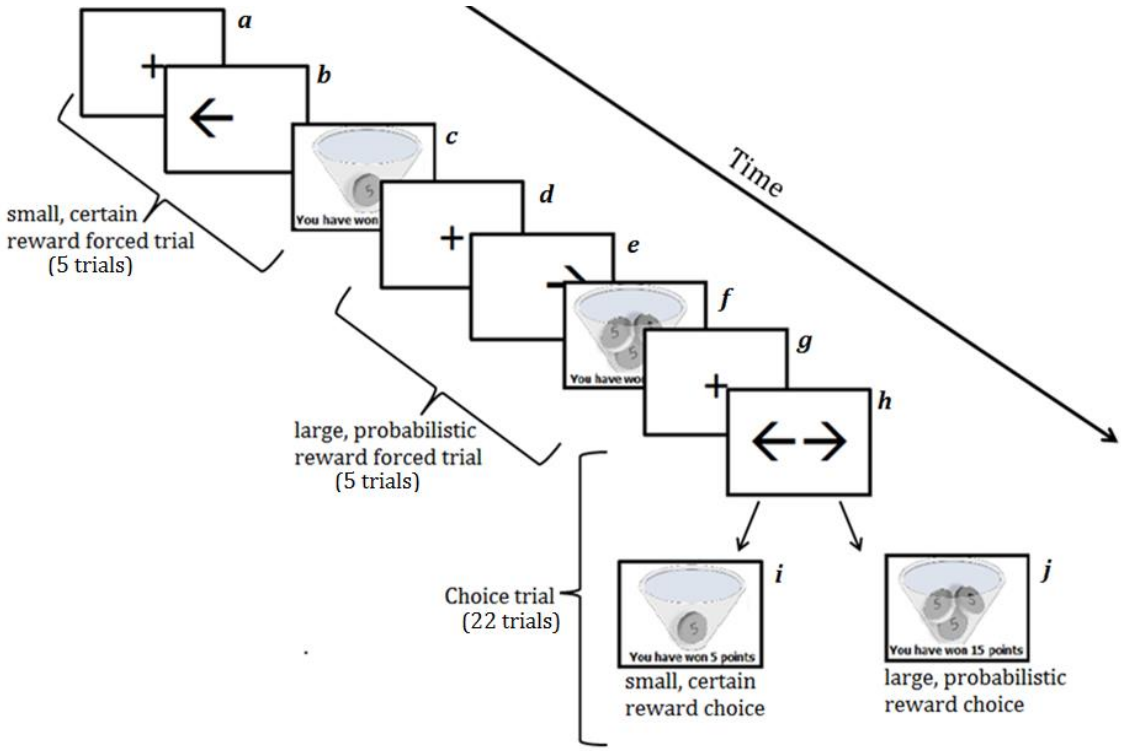


Figure 6.1: illustrates a single block (of four) of the program for the probability-discounting computerized task.

The delay-discounting program was made up of 5 blocks of 12 trials (4 forced, 8 choice trials). In each block, the delay before receiving the large reward changed (0, 4, 8, 16 and 32 seconds), but the small reward remained immediate (0 sec). If the participant selected the large reward, a screen would appear saying "you have X seconds left" counting down the associated delay (*figure* 6.2f & 4.2k). To ensure that participants would not select the small reward in order to leave the experiment sooner, they were informed that the program length was set. On selection of the small reward, the delay associated with the large reward would be added to the inter-block interval. If participants responded incorrectly to a forced trial, the delay associated with the large reward would be divided in two; half the delay would appear immediately as a penalty and the

other half was added to the inter-block interval. In this way, we ensured that all delay-discounting programs took the same time to complete, irrespective of reward choice.

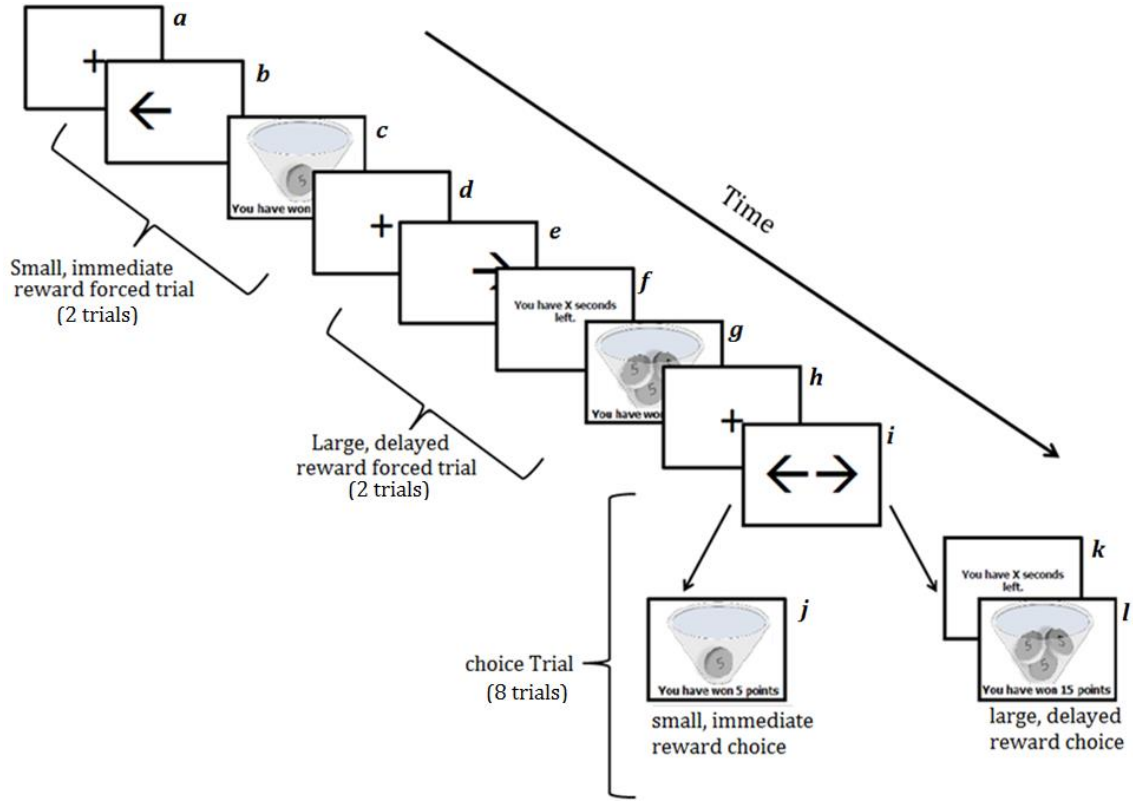


Figure 6.2: illustrates a single block (of five) of the program for the delay-discounting computerized task (note: as this diagram shows the trial sequence within a block it does not illustrate the inter-block interval).

6.4: Results:

6.4.1: Probability-discounting:

There was a significant main effect of *block*, $F(3, 36) = 21.47$, $p<.001$, meaning participants significantly differentiated the blocks and changed their responding accordingly. Bonferroni corrected post-hocs showed a significant difference between the 100 and the 33% ($p=.008$) and the 0% large, reward blocks ($p<.001$). There was no significant effect of the *Order* the blocks were presented in and no significant block by order interaction (see *figure 6.3*).

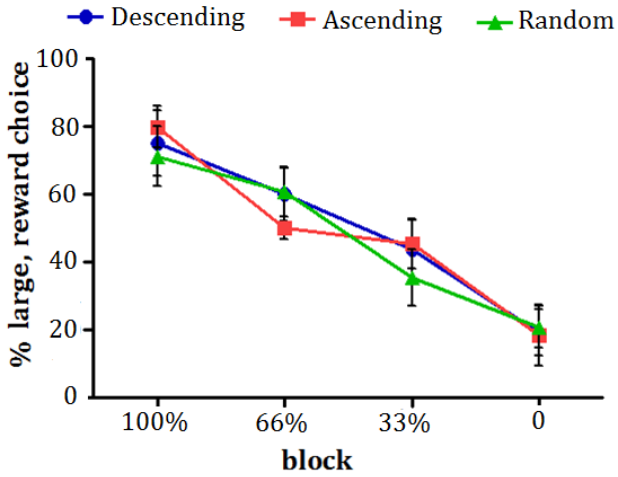


Figure 6.3: shows the proportion of choices of the large reward over the small but certain reward across *Blocks* as a function of *Order condition* (Ascending, Descending and random subjective cost). (Error bars show ± S.E)

6.4.2: Delay-discounting:

There was a significant effect of *block*, F (2.03, 22.35) = 5.80, p=.009. Least significant difference post-hocs showed a significant difference between the 0 and 16 sec (p=.009) and 0 and 32 sec delay (p=.009). There was again no significant sequence effect and no significant *block* by *order* interaction, (see *figure* 6.4).

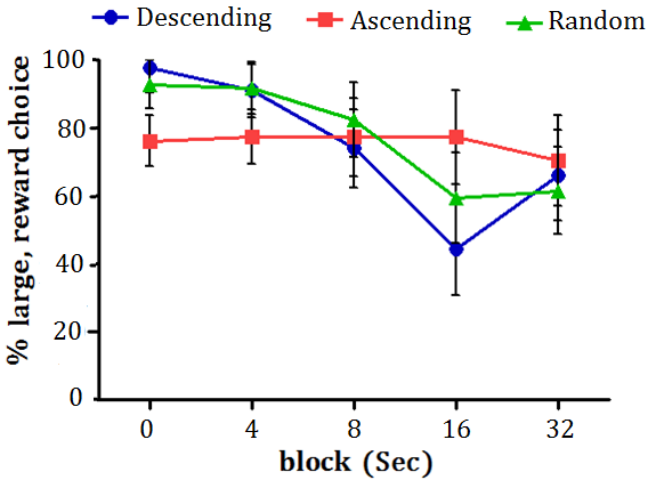


Figure 6.4: shows the proportion of choices of the large reward over the small immediate across *blocks* as a function of *Order conditions* (Ascending, Descending and random subjective cost). (Error bars show ± S.E)

6.5: Discussion

Three presentation orders for probability- and delay-discounting were examined to determine the influence on behaviour: ascending, descending and random subjective costs. Previous research had indicated that, in a delay-discounting task, an ascending sequence elicited more rapid preference reversals than a random or descending sequence (Robles & Vargas, 2008; Robles et al., 2009; Fox, Hand, & Reilly, 2008).

The results of the probability-discounting analysis revealed that participants were able to distinguish the reward contingencies. Furthermore, discounting across contingency blocks was shown to be similar irrespective of presentation order.

While, contrary to previous literature (Robles & Vargas, 2007; 2008; Robles, Vargas, & Bejarano, 2009), there was no significant difference in delay-discounting rates across presentation orders, discounting behaviour was much weaker in the ascending presentation order than random or descending sequences. However, analysis also revealed that, though participants were distinguishing between the *blocks*, and varying their behaviour accordingly for the random and descending sequences, the selection of the large, reward only dropped below 50% in the descending order 16 sec block (M=48.96, SE= 14.31). Meaning that notwithstanding the order of blocks, the subjective cost associated with the large, reward was insufficient to produce a reliable preference reversal. In order to induce one in future experiments, the delay blocks would need to be adjusted to increase subjective costs. As discounting tasks typically present subjective costs in ascending sequences (Epstein et al., 2003), the difference in response rates was not significant and discounting rate is known to be influenced by this factor, it will be beneficial to adapt the ascending protocol rather than use a descending or random sequence.

6.6: Experiment 6.2

As experiment 6.1 showed that the presentation orders did not significantly alter discounting rate for either probability or delay-discounting, we will maintain the block presentation order used previously in our animal experiment, ascending subjective costs, i.e. with the likelihood of receiving the large reward gradually decreasing across blocks and the delay before the large reward gradually increasing across blocks. Furthermore, as selection of the large reward did not drop below 50% during any delay block and there was no significant difference between the 0, 4

and 8 second blocks, we decided to increase the subjective cost associated with the large reward by including a further block of 64sec *in lieu* of the 4 second block used in the experiment 6.1.

As discussed in the introduction, rapid discounting probabilistic or delayed rewards has been termed impulsive (Ainslie, 2012; Kirby & Herrnstein, 1995; Green & Myerson, 2010). A highly utilised and well validated self-report measure of impulsivity is the Barratt Impulsivity Scale-11 (BIS-11) (Stanford et al., 2009). Mobini, Grant, Kass & Yeomans, (2007) found a positive correlation between delay-discounting and BIS-11 scores whereas no significant correlation between the BIS-11 and probability-discounting rate has been shown (Mitchell, 1999; Reynolds, Penfold & Patak, 2008). In order to examine the relation between the implicit computerised tasks described herein and trait impulsivity, the BIS-11 was included in experiment 6.2.

There is mixed evidence regarding the relationship between alcohol consumption and discounting behaviour. Probability-discounting rate has shown to be effected by acute exposure to alcohol, whereas delay-discounting has not (Bidwell et al., 2013). Conversely, individuals who frequently consume large quantities of alcohol have been shown to discount delayed rewards more rapidly than light-social drinkers (Vuchinich & Simpson, 1998; Field, Christiansen, Cole & Goudie, 2007; Jarmolowicz, Bickel, & Gatchalian, 2013). In order to assess the association between alcohol use and discounting behaviour the alcohol use questionnaire (AUQ; see general methods) was be included in subsequent experiments. It was hypothesised that weekly alcohol consumption and binge behaviour would be associated with rapid discounting of delayed, but not probabilistic, rewards.

Previous research into discounting has demonstrated that discounting rate can be influenced the participant's mood during testing (Hirsh, Guindon, Morisano & Peterson, 2010; Drichoutis & Nayga, 2013). Furthermore, previous research has indicated that steeper discounting rates are associated with an over-estimation of time (Baumann & Odum, 2012) and that contingency awareness is necessary for conditioned reinforcement (Field & Duka, 2001; Hogarth & Duka, 2006). During experiment 6.1, it was observed that a number of participants became irritable and it was hypothesized that the protocols may have induced this negative affect which might, in turn, have influenced discounting rates. In order to assess the influence of affect and to examine whether time perception differed across participants, visual analogue scales (VAS) measuring mood will be included in experiment 6.2 at the beginning and end of the computerized tasks.

Deprivation of a reinforcer has been shown to enhance reward value (Heyman & Monaghan, 1987), which consequently means that varying deprivation produces a similar effect to changing reward size (Ho, Wager, Bradshaw & Szabadi, 1997). Exposing an individual to a reward and allowing them to satiate themselves on it is referred to as devaluation (Holland, 1981). Experiments examining the relationship between probability discounting rate and devaluation have produced mixed results. While some studies have reported no significant effect of food deprivation on probability discounting rate (Cardinal & Howes, 2005; Cardinal, Robbins & Everitt, 2000). St Onge and Floresco (2009) found that rats satiated to a food reinforcer made more risky decisions in a probability discounting task than food deprived subjects. Similarly, when opioid deprived, human addicts discounted hypothetical heroin significantly faster than when they performed the task satiated (Bickel, Giodano & Badger, 2004).

Opioid withdrawal has been demonstrated to have a similar effect within a delay-discounting paradigm, discounting rates for money and heroin rewards were shown to be significantly faster when opioid deprived than when satiated in human participants (Giodano et al., 2002). In another delay-discounting task, nicotine deprivation has been shown to increases impulsive responding in smokers for cigarette and monetary rewards compared to in whilst satiated (Field, Santarcangelo, Sumnall, Goudie & Cole, 2006). Although, in a similar assessment, Yi and Landes (2012) found nicotine deprivation only increased impulsive responding in a delay discounting task for cigarette rewards and had no effect on delay-discounting for money or probability discounting rate for either money or cigarettes. In rats, water deprivation has been shown to effect the response time in a delay-discounting task but not discounting rate itself (Richards, Mitchell, Wit, & Seiden, 1997).

Van den Bergh, Dewitte, & Warlop (2008) examined the effect of devaluation on delay-discounting for monetary rewards by asking participants to indicate the combined total in their checking and savings account on a 9 point scale from €0 to either €400 (€50 increments; maintained) or €400,000 (€500 increments; devalued). When responding to the extreme of a scale (top or bottom) participants make inferences about their personal finances accordingly (Schwarz, 1999). Participants were also split into two groups; high and low sensitivity to reward. Participants who were highly sensitive to reward and in the deprived condition discounted delayed rewards significantly faster than counterparts in the satiated condition; suggesting that the effect of devaluation may be subject to individual differences to reward sensitivity. A further aim of this experiment was therefore to examine the effect of reinforcer devaluation before initiation

of the discounting task. In order to assess this, participants were pre-exposed to the reinforcer in order to lower its value, we expected discounting rate to be faster in those who had been pre-exposed than those who had not, i.e. participants in the devalued condition would switch from picking the large reward to the small reward more rapidly than those in the maintained condition.

6.7: Method

6.7.1: Participants:

54 participants, ranging between 18 and 37 years of age (*M= 20.94, SE=0.55),* were recruited (see general methods). There were 26 females (*M*=20.65, *SE*=0.74) and 28 Males (*M*=21.21, *SE*= 0.83)

6.7.2: Materials:

The probability and delay-discounting programs and two "training" (devaluation) programs, were written in e-prime 2. Data were analysed using IBM SPSS 21. The Medical history health questionnaire, Barratt Impulsivity scale, Alcohol use Questionnaire and Drug use questionnaire were presented on paper (see general methods). All computer programs were completed in an individual lab computer room. Responding was recorded using a serial response box (SRB) for the discounting programs. Participants used the mouse and keyboard to respond to the visual analogue scales (VAS).

6.7.3: Procedure:

Participants were presented initially with the consent form and information sheet outlining the structure of the experiment and their right to withdraw. If participants wished to continue they went on to complete the experiment in 3 phases:

Phase 1. Participants completed a Medical History, drug-use, alcohol use and Barratt impulsiveness questionnaires (see general methods section). Completion of this phase took on average 25 minutes and during this time, participants were informed that they were able to ask as many questions as they liked, so to ensure understanding and compliance with the procedures.

Phase 2: Participants were then brought into a testing room to complete a series of computer programs, the first of which was the between subjects devaluation manipulation; presented under the guise of a reaction time test. There were two versions of this task, one being designed to devalue the points (devalued) and the other was the control (maintained) condition. In both programs, participants were instructed to press the spacebar as quickly as possible when a black square appeared, and not respond when the grey square appeared. In the devalued condition,

participants were told they could win points for responding rapidly to the black squares, whereas no reference was made to points in the maintained condition. Irrespective of the rapidity of their responding, participants in the devalued condition received between 35 points and 55 points for each "correct" spacebar press (*figure 6.*5a). Conversely, those in the maintained condition, saw a blank screen for an equivalent duration (*figure 6.*5b).

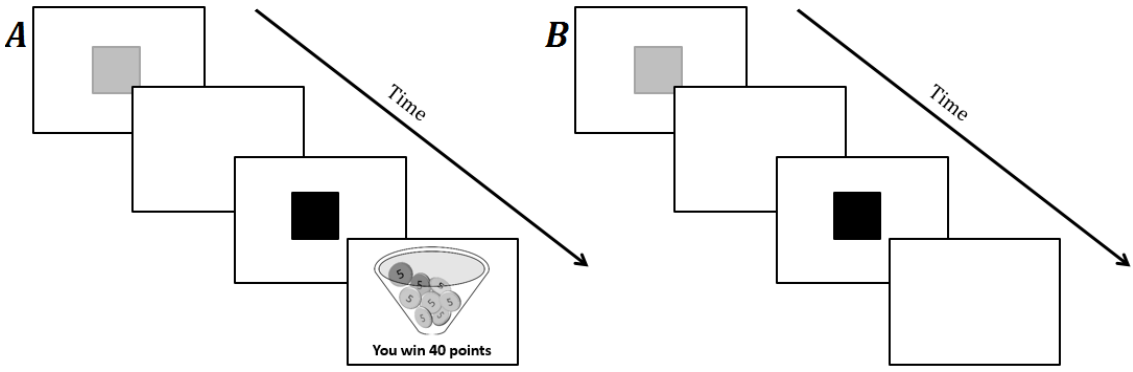


*Figure 6.*5: **A)** shows a hypothetical screen sequence from the devalued condition, wherein a participant has pressed the spacebar in response to a black square. **B)** Shows the same sequence in the maintained condition.

On completion of the devaluation program, participants were asked to complete a series of VASs on the computer; which measured mood (calm, happy, frustrated, tired, energetic, anxious, irritated, sad), evaluative conditioning, and an estimate of perceived task duration.

Phase 3: Once completed, participants began the discounting programs. Results from experiment 6.1 indicated no significant difference as a function of the order of choice presentation (cf. Robles & Vargas, 2008; Petri, 2001; Robles, Vargas & Bjarne, 2009), therefore an ascending subjective cost procedure was used for both measures: for the probability-discounting program this meant the likelihood of winning the large rewards decreased across blocks (100,66,33,0%) and in the delay-discounting program this means increasing the delay before the large reward receipt (0, 8, 16, 32 and 64 sec)

The discounting programs used were the same as those described for the for experiment 6.1, except that in the delay discounting procedure the 4 sec block was omitted and a 64 sec block was included as the longest delay. Participants completed both programs with the order of completion counterbalanced such that half the sample completed the delay-discounting program first.

On conclusion of the second discounting program, participants were again asked complete the VASs and were then debriefed and compensated for their time.

6.7.4: Data analysis:

6.7.4.1: Discounting Programs:

For both the probability and delay-discounting programs the outcome measure was the proportion of large, over small, reward choices and was calculated as a proportion or percentage of total responses made. As in experiment 6.1, these data were analysed untransformed.

6.7.4.2: Questionnaires:

For details on how questionnaire data was split see general methods section

6.7.4.2.1: Alcohol Use Questionnaire (AUQ; Townshend & Duka, 2002): Binger and Non-binger classification:

The average Binge score was 26.32 (*SE:* 2.79). There were 20 individuals with a score of ≤13 who were classified a "non-binger" (*M*=7.26, *SE*=1.24) and 24 with a score ≥ 33 was classified as a "binger" (*M*=44.63, *SE*=3.03). The overall average AUQ score was 43.51 (*SE:* 4.23). For bingers this was 69.15 (*SE:* 5.12) and non-bingers 17.83 (*SE:* 4.00).

6.7.4.2.2: Barratt Impulsiveness Scale classification, Version 11 (BIS-11; Stanford et al., 2009):

The average total BIS-11 score was 62.85 (*SE:* 1.49). 33 participants reported *normal* levels of impulsivity (*M*=61.58, *SE*=0.96), 12 reported being *highly impulsive* (*M*=77.92, *SE*=1.69) and 9 reported being *overly-controlled* (*M*=47.44, *SE*=1.16).

6.7.4.2.3: Drug Use Questionnaire (DUQ; Morgan, 1999; Nesic & Duka, 2006):

Twenty three participants indicated never to have used THC, 35 participants were drug naïve or single drug users and 35 were classified as poly users.

6.8: Results:

Greenhouse-Geisser and Huynh-Feldt corrections have been applied wherever Mauchley's test indicated the assumption of sphericity had been violated. Partial eta squared (partial η^2) effect sizes have been included after each significant effect to aid interpretation; based on the following benchmarks: a value of 0.02 or larger indicates a small, between 0.13 and 0.26 denotes a medium

and in excess of 0.26 is a large effect. Unless otherwise stated, follow on tests were Bonferroni corrected post-hocs.

6.8.1: VAS:

There was no significant main effects of devaluation or discounting program order on mood ratings. There was also no significant difference in estimation of task duration across program order (delay or probability program first) or BIS-11 classifications.

6.8.2: Probability-discounting Reward Choices:

6.8.2.1: Binge Classification*:*

Large reward choice was compared across *devaluation, Blocks* and *binge classification* and this showed a significant effect of *Block, F (*2.04, 97.84) = 39.36, $p<.001$, partial $\eta^2= .45$. The large reward was selected significantly more during the 100% ($M=79.73$, $SE=3.52$) than 66 ($M=60.63$, $SE=4.22$, $p=.002$), 33 ($M=48.21$, $SE=4.26$, $p<.001$) and 0 blocks ($M=29.56$, $SE=4.08$, $p<.001$).

6.8.2.2: BIS-11 classification*:*

Large reward selection was compared across *devaluation conditions*, *block*s and *BIS-11 classification* revealing a significant effect of *block F (2.18*, 104.43) = 40.58, $p<.001$, partial $\eta^2= .46$, the large reward was selected significantly more during the 100 block than 66 ($p= .003$), 33 and 0 blocks ($ps<.001$). There was a significant three way interaction between *block, devaluation condition* and *BIS classification*, *F (*4.35, 104.43) = 3.07, $p=.01$, $\eta^2=.11$. Further analysis revealed that there was a significant interaction between *block* and *devaluation condition* but only for the *highly impulsive* participants, *F (*1.79, 23.70) = 3.79, $p=.047$, $\eta^2=.28$. *Figure 6.6* shows that, irrespective of devaluation condition, *normal* and *overly-controlled* participants discounted the large reward across blocks, as did the 'highly impulsive across blocks in the maintained condition. In the devalued condition, there was no significant effect of block for highly impulsive individuals*;* as shown by the consistent selection of the large reward.

There were no other significant main or interaction effects of devaluation, Binge, BIS -11 or poly-drug classifications on reward choice.

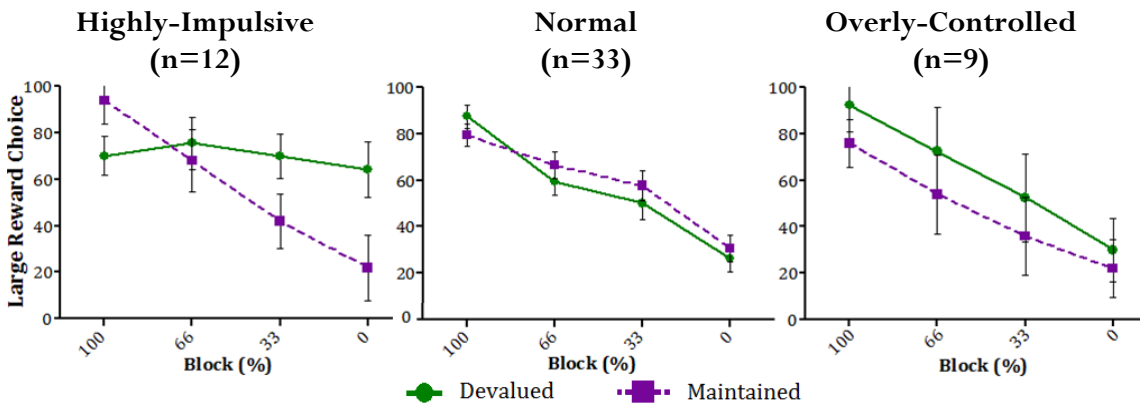


Figure 6.6: shows the shows proportion of choices of the large, reward over the small, certain reward, taken as a % of total choice trials, across *Blocks* (100,66,33 and 0%) split by *devaluation condition* and by *BIS-11 classification* (error bars show ± S.E)

6.8.3: Delay-Discounting Reward Choices:

6.8.3.1: Binge Classification:

The large reward choices were compared in a three-way mixed measures ANOVA (*devaluation condition* * block * *binge classification*). There was a significant effect of *block* on *large reward choice F* (2.76, 110.44) =9.99, $p<.001$, partial $\eta^2=.20$). The large reward was selected significantly more during the 0 than the 8 sec ($p=.008$), 16sec, 32sec and 64 sec block ($ps<.001$). There was no significant main or interaction effects of binge classification.

6.8.3.2: BIS-11 classification:

A three way mixed ANOVA (*devaluation conditions** *Block*BIS-11 Classification)* revealed a significant effect of *block, F* (2.99, 139.17) = 3.28, $p=.024$, partial $\eta^2= .06$. LSD corrected post-hocs revealed participants selected the large reward significantly more during the 0sec, than the 16 sec ($p=.032$) , 32sec ($p=.018$) and 64sec block ($p=.011$).

There were a significant main effect of *BIS Classification, F* (2, 48) = 4.05, $p=.024$, partial $\eta^2= .14$. Follow on tests revealed that 'overly-controlled' participants ($M=73.06$, $SE=7.69$) selected the large-reward more than the 'highly-impulsive' participants ($M=57.29$, $SE=6.66$) and significantly more than 'normal' participants ($M= 50.15$, $SE=4.02$, $p=.033$). Analysis of *figure 6.7* shows that the overly-controlled and highly impulsive participants continued to select the large delayed reward when 'normal' participants had begun to devalue it. Further analysis revealed that 'normal' participants significantly discounted the large reward across blocks *F* (4,128) = 8.66, $p<.001$, partial $\eta^2= .21$, whereas highly-impulsive and overly-controlled participants did not. There were no significant main or interaction effects of devaluation, Binge, BIS -11 or poly-drug classifications.

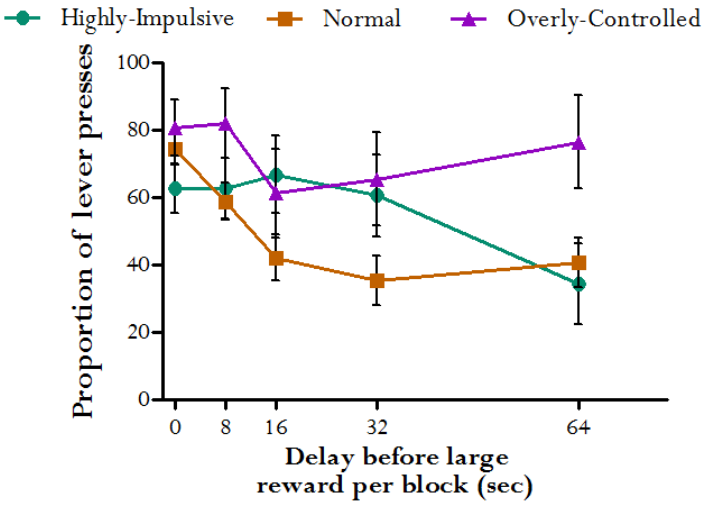


Figure 6.7: the non-significant interaction between BIS Classification, *devaluation condition* across *block* (error bars show ± S.E)

6.9: Discussion:

For both probability and delay-discounting procedures a significant effect of block was found, confirming that these tasks are the first to demonstrate discounting using an implicit learning procedure in humans. This study aimed to examine devaluation by allowing half of the participants to "win" a large number of points before the discounting tasks had begun. Depending on BIS-11 classifications, the devaluation condition appears to have acted as a prime to the overly-controlled participants when discounting on the basis of probability, as they selected the large reward more than those in the maintained condition. Conversely, in the highly-impulsive individuals in the maintained condition discounted the large reward across probability blocks, whereas those in the devaluation condition failed to show any discounting across contingency blocks. This result shows that for the highly-impulsive participants the peanuts effects, i.e. propensity to show more risk-seeking behaviour as the size of the reward decreases, was eliminated as a consequence of the devaluation manipulation but was unaffected in the maintained condition and all other BIS-11 classifications. However, the devaluation manipulation had no effect on delay-discounting.

Previous research has shown that those with a propensity to over-estimate the amount of time that has elapsed also show a tendency to rapidly discount delayed rewards (Baumann & Odum, 2012). Our results showed that irrespective of whether participants completed the probability- or delay-discounting procedure first, there was no difference in time perception across either

condition. This means that irrespective of program order, participants rated the duration of the tasks the same. It has been shown that an individuals' memory for an event can be biased by its most intense period (its peak) and by its finale (the end) (Kahneman, Fredrickson, Schreiber & Redelmeier, 1993). From a methodological standpoint, the failure to find a peak-end effect is beneficial in that it means that the discounting rates of participants were not influenced by the order in which they complete the programs.

A further aim of these experiments was to investigate the effect of priming on discounting behaviour Zauberman et al., (2009) showed that discounting rate could be influenced to be more rapid by priming participants to be aware of the passage of time. In the current experiments we aims to establish whether discounting rates can be influenced by priming state impulsivity using a priming task previous used by our lab (Caswell, 2013). Furthermore, we wished to ascertain whether these primes would influence the highly-impulsive participants differently to the overly-controlled participants.

6.10: Experiment 6.3:

Cognitive priming has been shown to unconsciously influence behaviour by activating related concepts or schema (Dafters, 2006; Guerrieri, Nederkoorn, Schrooten, Martijn, & Jansen, 2009; Zajonc, 2001). Guerrieri et al., (2009) established a mode of cognitive priming wherein the prime is presented as a memory test; a written passage, containing information about a fictitious individual was read aloud by the experimenter to each participant. The aim of this experiment is to establish whether priming participants can influence their discounting behaviour. In addition to this, it also aims to examine whether there is any relation between discounting rate, trait impulsivity (BIS-11 score) and state impulsivity as induced by the prime.

6.11: Method:

6.11.1: Participants:

We tested 65 participants (33 female; *M*=19.21, *SE*=1.48; 32 Male; *M*=21.66, *SE*= 1.77), ranging between 18 and 42 years of age (*M= 20.42, SE=1.15)* that were recruited by poster, the University of Sussex subject pool (SONA) or word of mouth. Participants were compensated for their time with £6 an hour or equivalent course credit.

6.11.2: Questionnaires

6.11.2.1: Alcohol Use Questionnaire (AUQ) Binger and Non-binger classification:

The average Binge score was 22.45 (*SE:* 3.01). There were 22 individuals with a score of ≤8 who were classified a "non-binger" (*M*=3.39, *SE*=0.68) and 21 with a score ≥26 was classified as a "binger" (*M*=50.12, *SE*=5.21). The overall average AUQ score was 33.40 (*SE:* 4.06). For bingers this was 69.84 (*SE:* 6.97) and non-bingers 6.893 (*SE:* 1.38).

6.11.2.2: Barratt Impulsiveness Scale Version 11 (BIS-11) classification :

Forty two participants reported *normal* levels of impulsivity (*M*=61.88, *SE*=0.90), 14 reported being *highly impulsive* (*M*=79.29, *SE*=2.05) and, finally, 9 reported being *overly-controlled* (*M*=47.33, *SE*=1.25).

6.11.2.3: Drug Use Questionnaire (DUQ):

Sixteen participants had not tried any THC based products before, there were 34 poly drug users and 32 single drug using or drug naïve participants

6.11.3: Materials:

The materials used in this experiment were the same as the previous experiment, but with the addition of the stop signal task and the priming materials (see appendix 3: 3.1).

6.11.4: Procedure:

The procedure for this experiment was the same as experiment 6.2, except for the inclusion of a between subjects priming condition and a test of response inhibition using a traditional stop-signal task.

6.11.4.1: The stop signal:

The Stop Signal task is a measure of a measure of motor inhibitory control (Logan, 1994) and was included so that participants' latency to respond could be compared across prime conditions in order to ascertain that reaction times did not differ before the prime condition.

The stop signal runs as follows, a fixation cross is presented (1200-1500ms) followed by a green arrow (800ms), this is the "go-signal'. Participants were asked to indicate the direction the arrow was pointing (left or right) using the keyboard. During a quarter of the trials, the arrow changed colour from green to red, this constitutes the 'stop-signal'. On these trials, participants need to withhold their responding (i.e. not indicate the direction). The first stop signal was presented 200ms after the onset of the green arrow but throughout the subsequent trials, the onset of the

stop signal (stop signal delay or SSD) depended on the accuracy of the participants previous responding; if they correctly inhibit their response the SSD decreased, making the subsequent trial easier (Verbruggen & Logan, 2009). The outcome variables from this task include correct and incorrect response rates, latency to indicate arrow direction, omissions and stop signal latency; with large stop signal latency indicating poor inhibitory control which is associated with higher levels of impulsive behaviour. Following the stop signal task, participants were asked to record their current mood using the first visual analogue scales.

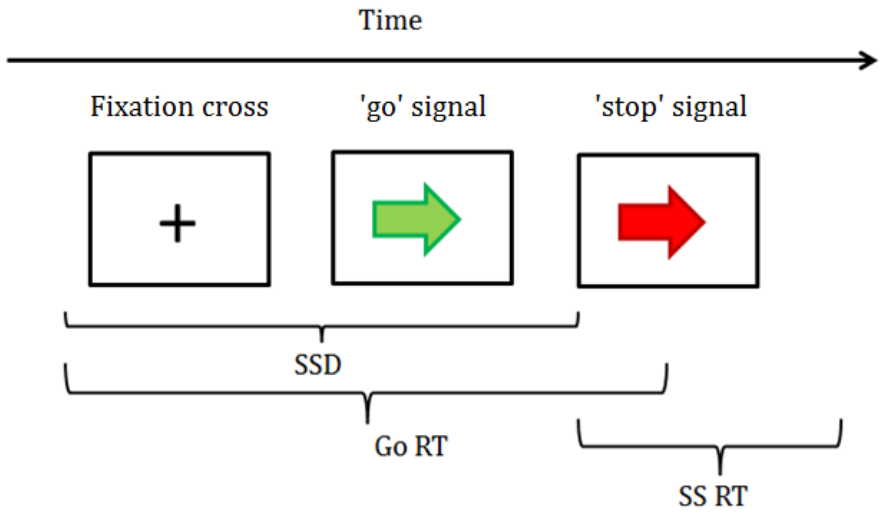


Figure 6.8: shows the sequence of screens of the stop signal task. The fixation cross was followed by a green arrow. The stop signal delay (SSD) represented the amount of time until the go signal turns red becoming the stop signal (SS, this occurs in 25% of trials. The SSD is not constant but changes depending on previous responding. The sequence shown here shows when a participant has successfully inhibited their response as the stop signal response time (SSRT) continues beyond the go latency (go RT).

On completion of VASs, participants were read a passage by the experimenter; this was the priming manipulation (see appendix 3.1). The passage described a fictional person and participants were asked to memorize the details about the person in preparation for a memory test, which would be administered after completing all the computer tasks. In fact, there was no memory test and instead the characteristics of the fictional individual were the three levels of the priming manipulation: speed, accuracy and none (control) (Guerrieri et al., 2009). This manipulation aimed to assess whether either response choice is susceptible to a prime induced speed/accuracy trade-off. Between each computer program the experimenter reminded the participants to rehearse as many details from the story as possible, in preparation for the memory test.

6.12: Results:

Analysis of results using Kolmogorov-Smirnoff tests revealed that response on the large reward lever was significantly non-normal across all blocks for both probability and delay-discounting programs. A log transformation corrected for non-normality for the delay-discounting program, however, non-normality could not be corrected for the probability-discounting program, therefore raw data was used in statistical analysis. All graphs show data in untransformed form.

6.12.1: VAS:

There was no significant effect of devaluation or discounting program order on mood ratings. There was also no significant difference in estimation of task duration across program order (delay or probability program first) or BIS-11 classifications.

6.12.2: The effect of *discounting procedure order* and *Prime* on Response choice:

The implicit priming manipulation was presented once, at the beginning of the testing session. As the order of the discounting procedure was counterbalanced across participants (i.e., half the subjects completed the delay-discounting followed by the probability-discounting, and the other half the order was reversed), the data were analysed for interactions between the *discounting procedure Order* and *Priming* condition. For both probability- and delay-discounting, there were no significant main or interactions effects between block, program order and prime on response choice.

6.12.3: Stop-Signal

Results from the stop signal task revealed that there were no significant differences in stop signal reaction time (SSRT), go accuracy or go reaction time across levels of Prime (control, accuracy and speed) or Devaluation (Maintained, devalued). This means that we can be confident that any differences observed in reaction times in the probability or delay discounting task are the result of the prime manipulation and not the result of significant differences in participants' baseline speeds (see Table A4.1 in appendix).

6.12.4: Probability-discounting:

A four way mixed measures ANOVA compared large reward choice across devaluation condition, prime, block and BIS classification, revealed a significant main effect of *Block*, $F(2.02,60.62)=39.80$, $p< .001$, $\eta^2=.57$. Planned comparisons show the large, reward was selected significantly more in the 100% block compared to the 66% ($p<. 001$, $\eta^2= .56$), 33% ($p<. 001$, $\eta^2= .70$) and 0% *blocks* ($p< .001$, $\eta^2= .71$). *Figure* 6.9 shows participants demonstrated

rapid discounting of the large reward option as uncertainty increased i.e. its subjective cost was too high. There were no significant main or interaction effects of devaluation, Binge, BIS -11 or poly-drug classifications.

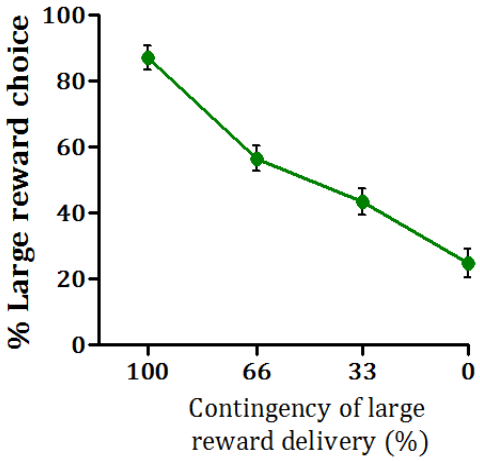


Figure 6.9: indicates the proportion of large variable reward choices declined significantly across the blocks. (Error bars show ± S.E)

6.12.5: Delay-discounting:

A mixed measures ANOVA (*Block * Devaluation Condition * Prime * BIS classification)* revealed a significant effect of *block*, F (4,192) =14.46, p<.001, η^2=.23. Contrasts revealed that compared to baseline (i.e., choice at 0 sec) there was a significant decrease in large reward selection at 32 sec (p<*.001,* η^2=.32) and 64 sec delay (p<*.001,* η^2=.35). *Figure 6.10*, shows that selection of the larger reward declines across *blocks,* as the associated subjective cost produces discounting behaviour.

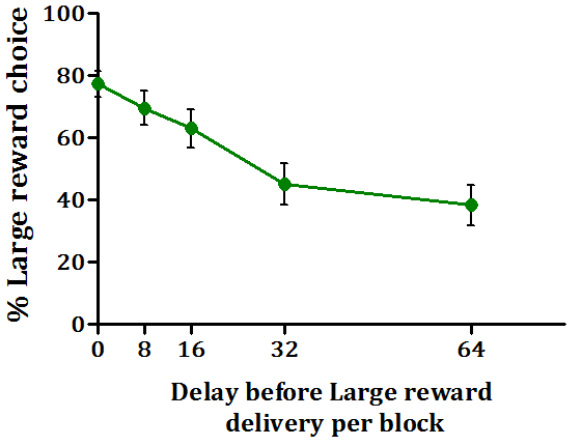


Figure 6.10: selection of the large, delayed choice, over the repeated measures variable *block* (error bars show ± S.E)

There was a significant interaction between the variables *Block, Devaluation Condition* and *BIS-11 classification*, F (8, 192) = 2.25, p=.026, η^2=.09. However, follow on inferential statistics

examining this interaction were all non-significant suggesting that this significant interaction may be the result of the small number of participants in each level of the devaluation manipulation in the highly impulsive (devalued: n=9, maintained=5) overly-controlled (devalued: n=5, maintained=5) groups. Therefore, all further analysis of this interaction is descriptive and should be interpreted with caution. Analysis of *figure 6.11* indicates that *devaluation condition* had a differential effect across *BIS* classifications. Those participants classified as 'normal' showed very little differentiation across devaluation conditions. The devaluation manipulation was most effective in those designated as 'overly-controlled'; those in the devaluation condition selected the large, reward less often than those who were in the maintained condition. Finally, those in the devalued condition who were classified as 'high impulsive' showed typical discounting of the large reward across *blocks*, as the subjective cost increased. However, in the maintained condition, there was a gradual increase in large reward choice across the first 3 blocks (0, 8 and 16 sec delay), when the subjective cost is low but as the delay increases to 32seconds, there is a rapid switch to selecting the smaller, immediate reward over the delayed, large reward.

There were no significant main or interaction effects of devaluation, Binge, BIS -11 or poly-drug classifications.

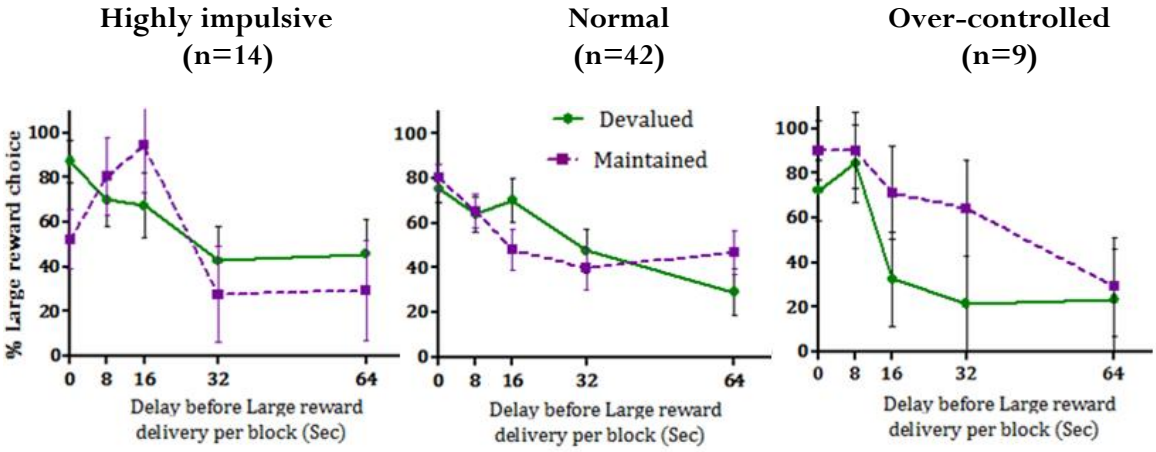


Figure 6.11: the interaction between *devaluation condition, Block* and *BIS-11 classification* on large reward choice in participants (error bars show ± S.E)

6.13: Discussion:

As in experiment 6.2, for both probability and delay-discounting procedures a significant effect of block was found. This experiment also aimed to examine the effect of priming on discounting

behaviour, however, the prime condition failed to have any effect on the utility of the large reward and the proportion of large reward choices was the same across accuracy, speed and control conditions.

This study also aimed to examine whether the rate at which the large, delayed points reward were discounted would be influenced by winning a large number of points before the discounting tasks had begun. There was no main effect of devaluation in either the probability or delay discounting task suggesting large reward utility was unaffected by pre-exposure to the points animation. There did appear to be a differential effect of the devaluation manipulation across the BIS-11 classifications for delay-discounting. However, this finding could not be supported by statistics therefore must be interpreted with caution. Contrary to experiment 6.1, those in the devalued condition discounted the delayed rewards more rapidly than those participants in the maintained condition but only if the participants were "overly-controlled". Interestingly, high-impulsive participants in the maintained condition selected the large reward at increasing rates for the first three blocks and then showed a rapid preference reversal at the 32second block. Whereas, highly impulsive participants in the devalued condition discounted the large reward across blocks. For probability-discounting, there was no effect of the devaluation manipulation either overall or between BIS-11 classifications.

As in experiment 6.2, there was no difference in estimation of duration of the tasks between those who completed the discounting or probability-discounting tasks first or across BIS-11 classifications.

6.14: General discussion:

The first aim of this series of experiment was to establish a human equivalent to existing non-human animal delay and probability-discounting paradigms based on the Evenden and Ryan (1996) procedure. In these tasks, participants needed to learn the association between a response choice and their associated reward and penalties via forced trials and experience the consequences of their choices. For both probability and delay-discounting procedures a significant effect of block was found in all three experiments, confirming that these tasks are the first to demonstrate discounting using an implicit learning procedure in humans.

In previous research using points as reinforcers the points have been directly exchangeable for monetary rewards (Logue et al., 1990) and that participants were indifferent between the small and large reward (Hyten et al., 1994). Based on the protocol of Hyten et al. (1994), these two experiments used a novel points animation which showed 5 point "coins" falling into a funnel, with the aim of increasing the salience of the reward and demonstrating clearly the discrepancy between the small and large reward choices. The results of the current experiments showed that participants will respond for, and discount, computerized points alone.

The next aim of experiments 6.2 and 6.3 was to assess the influence of devaluation on discounting behaviour, this was done by pre-exposure to the reward. In both experiments the devaluation manipulation acted as a prime to the majority of participants, as individuals in this condition tended to pick the large reward more than their counterparts in the maintained condition. In the probability discounting task in experiment 6.2, highly impulsive individuals in the devalued condition did not demonstrate more rapid discounting of large rewards as the probability of reward receipt declined, indicating that the devaluation eliminated the peanuts effect. However, this result was not replicated in probability discounting task in experiment 6.3 or effect the magnitude effect in the delayed-discounting task in either experiment 6.2 or 6.3. A potential explanation for why the devaluation manipulation did not affect behaviour is that, while participants would see a total of earned points between blocks, this did not include the points won during the devaluation stage. If their score had included the devaluation points from the outset, the repeated reminders of their current total might have induced a more rapid preference reversal. Furthermore, unlike Van den Bergh et al. (2008), participants did not have a reference to compare their scores to. Therefore, this manipulation might have been more effective if the participants' received a score for both the maintained and devalued condition but that those in the devaluation condition were told they had performed better than most others and those in the maintained condition were told the reverse.

Similarly, the prime condition did not affect behaviour as anticipated; more rapid discounting of reward utility in the speed condition and slower discounting of utility in the accuracy condition was not observed compared to the control condition. A possible reason for this is that the prime contained too few details about the fictitious individual, and that inclusion of more details or adjectives might have had a more noticeable effect on behaviour. Another possibility is that the prime was only presented once, at the beginning of the tasks which were quite lengthy. The

participants were reminded between blocks by the experimenter to rehearse the material between blocks, but without re-exposure to the stimuli the participants may have been rehearsing filler details and failing to pick up on details key to the manipulation.

Finally, a tendency to rapidly discount delayed reward utility is associated with a propensity to over-estimate the amount of time that has elapsed (Baumann & Odum, 2012). Based on this there were two predictions in the current experiments: firstly, that those who completed the delay-discounting program second would over-estimate the duration of the task compared to those who completed the probability-discounting task first, due to the peak-end effect (Kahneman et al, 1993). Secondly, that those who scored highly on the BIS-11 (highly impulsive individuals) would over-estimate the passage of time compared to 'normal' or over-controlled counterparts. Results showed no difference in time perception, in either experiment 6.2 or 6.3, between program order conditions or BIS classifications. From a methodological standpoint, the failure to find a peak-end effect is beneficial as it means that the discounting rates of participants were not influenced by the order in which they completed the programs. The failure to find a difference in time-perception across BIS-11classifications indicates that perception of the passage of time may not be related to trait impulsivity.

Chapter 6: probability and delay-discounting in humans

- The results of these experiments show consistent reliable delay- and probability-discounting behaviour using a novel, implicit computerized task
- Found that discounting behaviour was not affected by the order blocks were presented in
- In experiment 6.2, for the delay-discounting protocol, the devaluation had a significantly differential effect across levels of BIS-11 classifications, acting as a prime in the overly-controlled participants.
- In experiment 6.2, for the probability-discounting paradigm, the devaluation had a significantly differential effect across levels of BIS-11 classification having no effect in the normal or overly controlled participants but supressing discounting behaviour in the highly impulsive participants.
- In experiment 6.3, there was no effect of prime on choice behaviour
- In experiment 6.3, for the delay-discounting protocol, the devaluation had a significantly differential effect across levels of BIS-11 classifications, supressing responding in the overly-controlled participants.
- There was no relation between discounting behaviour and alcohol consumption at any point.

7. Examining the relationship between the *BIS-11* and probability- and delay-discounting using online questionnaires

Abstract:

Two online questionnaires were used to examine the association between trait impulsivity (as measured by the *BIS-11)* and delay (n=346) and probability-discounting (n=244). Based on previous findings, alcohol use (binge drinking habits and units of alcohol consumed per week), smoking status, age and sex were also included. Delay, but not probability, discounting rate was significantly predicted by overall BIS-11 score and the motor and cogn0itive complexity subscales. Results reveal a significant difference in discounting rates across smoking status for both probability- and delay-discounting but no relationship between discounting rates, alcohol use and age.

Keywords: probability- and delay-discounting, trait impulsivity, BIS-11, online, alcohol, smoking

The concept of *discounting* refers to how a reward can systematically lose value as a result of an associated subjective cost such as effort or low probability of receipt. This process of individual devaluation can be studied using choice procedures wherein participants are asked to select between a small and a large reward. The associated cost of the large reward is then incrementally adjusted in order to induce a *preference reversal*. This is when an individual changes their choice from one option to the other, as the cost affiliated with their initial choice becomes too high; put another way, when the rewards are rendered subjectively equal (Green & Myerson, 2004).

Delay-discounting refers specifically to how a reward loses value as a function of the delay before receipt (Madden & Bickel, 2010). Whereas, the term *probability-discounting* applies to the decrease in subjective value of a reward as a result diminishing probability of receipt (Yi, Mitchell & Bickel, 2010). As both probability- and delay-discounting are best described by a *hyperbolic function* (Ainslie, 1975; Mazur, 1987; Richards, Zhang, Mitchell & de Wit, 1999), it has been suggested that they reflect a single process of prospect evaluation (Prelec & Loewenstein, 1991), which has

evolved to optimise foraging (Stevens & Hauser, 2004). Delay-discounting has been described in terms of probability-discounting, in that the lower the probability the higher the number of attempts to secure the reward which consequently increases the delay before receipt (Rachlin, Siegel & Cross, 1994). Conversely, probability-discounting can be considered in terms of delay-discounting if the delay before reward receipt is taken to be indicative of reward probability; the longer the delay the less likely the reward will be acquired.

However, the fact that reward size has the opposite effect on discounting rates in probability- and delay-discounting tasks has been used as evidence probability- and delay-discounting reflect distinct processes (Christensen, Parker, Silberberg, & Hursh, 1998). Probabilistic rewards are discounted more rapidly the larger the reward size but small delayed rewards lose subjective value more rapidly than large delayed rewards (Green, Fry & Myerson, 1994; Kirby & Maraković, 1996; Kirby, Petry & Bickel, 1999; Green, Myerson & McFadden; 1997). This has been repeatedly demonstrated using *binary-choice* questionnaires; which have been shown to be well-validated (de Wit, Flory, Acheson, McCloskey, & Manuck, 2007) for both delay (Kiry & Maraković, 1996; Kirby et al., 1999) and probability-discounting (Madden, Petry & Johnson, 2009). Such measures involve participants being presented with a list of randomized binary choices and asked to select between each of the reward amounts and their related costs. Binary choice questionnaires can be divided into multiple subscales, allowing for the examination of overall discounting rate and discounting rate across multiple reward magnitudes (i.e. small, medium and large). Each of these subscales represents a short form of the complete questionnaire and, therefore, can be used as measures of validity (Myerson, Baumann & Green, 2014).

It has been suggested that steep discounting of delayed reinforcers plays a role in addictive processes (Bickel, MacKillop, Madden, Odum &Yi, 2015). This hypothesis is supported by the observation that failure to delay gratification in adolescence is indicative of subsequent drug-taking in humans (Audrain-McGovern et al., 2009; Kim-Spoon, McCullough, Bickel, Farley, &Longo, 2014) and rodents (Koffarnus &Woods, 2013) and that the rapidity with which delayed rewards are discounted has been shown to correlate with degree of substance abuse (MacKillop, Amlung, Few, Ray, Sweet & Munafò, 2011; Yi, Mitchell & Bickel, 2010; Andrade & Petry, 2012). Addicts typically discount delayed-rewards more rapidly than non-addicts (Kirby et al., 1999; Petry & Casarella, 1999; Heil, Johnson, Higgins & Bickel, 2006) and, while the same effect has not been consistently replicated with probability-discounting (Andrade & Petry, 2012), this has led to increased interest in discounting procedures (Bickel et al., 2015). Discounting rates are

commodity specific (Odum, Baumann & Rimington, 2006; Lawyer, Williams, Prihodova, Rollins, & Lester, 2010); for example, drug dependent individuals have been shown to discount delayed drugs more rapidly than delayed money (Coffey, Gudleski, Saladin, Brady, 2003; Petry, 2001b; Madden, Petry, Badger & Bickel, 1997).

The association between discounting delayed rewards and drug taking is well-established within clinical populations (for reviews see Reynolds, 2006; Bickel & Marsch, 2001; de Wit, 2009); addicts typically discount delayed-rewards more rapidly than non-addicts (Kirby et al., 1999; Petry & Casarella, 1999; Heil et al., 2006). Within the general public, the same effect has been observed using smokers (Amlung & MacKillop, 2014; Baker, Johnson, & Bickel, 2003; Reynolds, 2004; Odum, Madden, & Bickel, 2002; Yoon et al., 2007; Reynolds, Richards, Horn & Karraker, 2004); smokers discount delayed cash (Businelle, McVay, Kendzor & Copeland, 2010; Bickel, Odum & Madden, 1999) and health rewards more rapidly than non-smokers (Baker et al., 2003). However, the same effect has not been shown consistently with probability-discounting (Andrade & Petry, 2012). The nature of the relationship between delay-discounting and smoking remains unclear; it is possible either that rapid discounters are more likely to smoke or that smokers are more likely to discount rapidly. While duration of smoking is uncorrelated with delay-discounting (Reynolds, 2004), frequency of smoking throughout the day negatively correlates with delay-discounting rate (Ohmura, Takahashi & Kitamura, 2005; Reynolds, 2004). Also, Audrain-McGovern et al. (2009) showed that rapid discounting of future rewards is a predictor of smoking acquisition. Delay-discounting has also been shown to be subject to change if addiction worsens, or improve if the individual is taking part in an effective intervention (Bickel, Koffarnus, Moody, & Wilson, 2014). The relation between probability-discounting and smoking behaviour is less clear, with some studies showing no relationship (Mitchell, 1999; Ohmura et al., 2005) and others showing that smokers discounted probabilistic rewards more rapidly than non-smokers (Reynolds et al., 2004)

In both human and non-human studies, alcohol consumption significantly effects discounting behaviour. Heavy-social and problem drinkers discount delayed rewards more rapidly than light-social drinkers (Vuchinich & Simpson, 1998; Field, Christiansen, Cole & Goudie, 2007; Jarmolowicz, Bickel, & Gatchalian, 2013). In non-human animal models, alcohol preferring mice demonstrate more rapid discounting of future rewards than low alcohol preference animals (Oberlin &Grahame, 2009). Furthermore, early exposure to alcohol induces more rapid discounting in animal models (Evendan & Ryan, 1999; Tomie, Aguado, Pohorecky & Benjamin,

1998) and correspondingly, in humans, early-onset alcoholics discount rewards more rapidly than late-onset fellows (Dom, D'haene, Hulstijn, & Sabbe, 2006).There is some evidence to suggest that alcoholics' discounting rates will decrease after a period of abstinence; currently-abusing alcoholics discounted hypothetical money and alcohol more rapidly than abstaining-alcoholics and never-drinkers (Petry, 2001a; Bjork, Hommer, Grant & Danube, 2004). Likewise, Mitchell, Fields, D'Esposito, & Boettiger (2005) revealed that non-drinking controls discounted future rewards less than abstinent-alcoholics. By contrast, Kirby and Petry (2004) found no difference in the discounting rates of alcoholics and controls, but it should be noted that, unlike Petry (2001a), the classification to identify alcoholics in this study did not reach the *DSM-IV* criteria and that smoking status within the alcoholic samples was not reported in a number of the studies described here, which could contributed to the effect of alcohol on discounting rate (Yi, Mitchell & Bickel 2010). In social drinkers, alcohol consumption increases risk seeking in a probability, but not delay-discounting, task (Bidwell et al., 2013). Similarly, binge drinkers completed more impulsive responses than non-binge drinkers in the Iowa gambling task (Goudriaan, Grekin, & Sher, 2007) but the relationship between discounting rates, either delay- or probability-, and binge drinking in adults has, at the time of writing, yet to be examined.

Due to the correlations between discounting rate and propensity to take drugs, it has been suggested that discounting is a dimension of impulsivity (McKillop et al., 2011); with those who discount quickly being termed 'impulsive' and those who discount more slowly being deemed 'risk-averse' (for a review see Perry & Carroll, 2008). Impulsivity is a multi-faceted construct (Caswell, 2013) known to be associated with a number of maladaptive, psychological disorders (Alessi & Petry, 2003) and impulsive individuals can be thought of as those who will concede excessive long-term costs in exchange for modest short-term gains (Baumeister & Scher, 1988). Arguably, the most administered self-report impulsivity questionnaire is the Barratt Impulsivity Scale-11 (BIS-11) (Stanford et al., 2009). This 30 item scale assesses trait impulsivity and can be broken down into three primary, and six secondary, subscales: *Attention (a*ttention, cognitive instability), *Motor* (motor, perseverance) and *Non-planning (*cognitive complexity, self-control); with higher scores indicating higher impulsivity (Patton, Stanford & Barratt, 1995). Scores on the BIS-11 are internally consistent and correlate highly with other self-report measures of impulsivity (Stanford et al., 2009). Furthermore, overall scores on this BIS have been shown to significantly differ across heavy and light drinkers (Papachristou, Nederkoorn, Havermans, van der Horst, & Jansen, 2012) and smokers and non-smokers (Reynolds et al., 2007).

Studies examining the relation between probability-discounting and BIS-11 scores are limited but show no significant correlation between the two (Mitchell, 1999; Reynolds, Penfold & Patak, 2008). Whereas, overall *BIS-11* score has also been shown to positively correlate with delay-discounting rate (Mobini, Grant, Kass & Yeomans, 2007). In addition, the non-planning subscale of the BIS-11 has been shown to positively (de Wit et al., 2007) and negatively (Baumann & Odum, 2012) correlate with and, to be a significant predictor of (Koff &Lucas, 2011), delay-discounting rate. All the studies analysing the relation between BIS-11 score and discounting rate have relied on adolescent and undergraduate student sampling, with the exception of de Wit et al. (2007), therefore, it would be beneficial to examine the relation between trait impulsivity and discounting rate in a large diverse sample.

Research into the field of discounting has revealed that there are extensive individual differences in the propensity to discount rewards (Anderson & Woolverton, 2005; Shamosh et al*.,* 2008; de Wit et al*.,* 2007; Reimers, Maylor, Stewart, & Chater, 2009; Ersner-Hershfield, Garton, Ballard, Samanez-Larkin, & Knutson, 2009). While some studies have reported finding that males discounting rewards more rapidly than females (Kirby & Maraković, 1996), subsequent investigations have failed to replicate this effect (Mitchell, Fields, D'Esposito & Boettiger, 2005; Odum & Baumann, 2010; de Wit et al., 2007). A more robust finding is that discounting rate changes with age; shown to be most rapid during childhood but to decrease across lifespan (Olsen, Hooper, Collins & Luciana, 2007; Green et al., 1994; Green, Myerson & Ostaszewski, 1999b). Overall BIS score has also been shown to reliably decline with age (Steinberg, Cauffman, Banich, Graham & Woolard, 2008; Spinella, 2007) which suggests delay-discounting and trait impulsivity might be related.

Due to the reliance on adolescent and undergraduate student samples in existing research, the first aim of this investigation was to examine the association between discounting rate, smoking and drinking behaviour, specifically binge drinking, within a large non-clinical population. Secondly, to explore the relation between delay- and probability-discounting and trait impulsivity, as measured by the BIS-11; whilst accounting for age and sex changes. Internet based questionnaires have been shown to reach diverse samples of participants across factors such as age, socioeconomic status, geographical location and gender (Gosling, Vazire, Srivastava, & John, 2004). Research has shown that internet based questionnaire responses do not differ pen-and-paper results (Gosling et al., 2004; Smith & Hantula, 2008). Moreover, there is evidence that increasing social distance encourages participants' honesty about socially stigmatized behaviours,

such as alcohol use (Aquilino, 1994) and that internet based assessments in particular, increase participants' sense of anonymity (Epstein & Klinkenberg, 2001). It is also important to note, that failure to complete online questionnaires, known as *drop-out rate,* can reach as high as 80% (O'Neil, Penrod, & Bornstein, 2003), meaning that structuring the paradigm efficiently is paramount. For this reason, we intend to measure the probability- and delay-discounting rates separately, so as to minimize questionnaire length. Based on previous research, we would expect that preference reversals in probability- and delay-discounting measures to occur earlier, indicating decision-impulsivity, in binge-drinkers than non-bingers. Similarly, we would expect smokers to discount more rapidly than non-smokers, in both discounting measures. Finally, we would expect, based on previous research (Olsen, Hooper, Collins & Luciana, 2007; Green et al., 1994; Green, Myerson & Ostaszewski, 1999b), discounting rate to decline with age and for there to be a correlation between discounting rate and the *non-planning* primary-subscale of the BIS-11.

7.2: Method:

7.2.1: Participants:

7.2.1.1: Delay-discounting:

There were 346 participants (226 female), aged 18-64 (M= 31.31, SE= 0.67). When a median split is applied to age, 76.59% of participants were aged 18-39. There were 127 smokers and 63 ex-smokers.

7.2.1.2: Probability-discounting:

The 244 participants (173 female) were aged 18-61. When a median split is applied to age, 89.33% of participants were aged 18-39. There were 87 smokers and 32 ex-smokers.

7.2.2: Materials:

Both questionnaires began by asking participants a series of personal details including sex, age, whether or not participants were taking prescription medications, an estimate of number of units of alcohol consumed every week and whether or not they currently smoked, have quit or have never smoked.

Following this, one of the discounting questionnaires was presented.

7.2.2.1: Delay-discounting:

A reproduction of the Kirby, Petry & Bickel (1999) 27 item questionnaire was presented in a table. Participants were asked to read the item, e.g. "*would you prefer £12 today or £75 in 8 months?"* and then check a box to indicate whether they chose the small-sooner reward or the large-later reward for each item (see appendix 1: 1.2 for reproduction and general methods for details on analysis). Questions were presented in the same random order used in the original procedure.

7.2.2.2: Probability-discounting:

Madden, Petry & Johnson's (2009) 30 item probability-discounting questionnaire was included in a table (see appendix 1: 1.3 for reproduction and general methods for details on analysis). The questionnaire includes items such as "*would you prefer £20 for sure or a 1-in-10 chance (10%) of winning £80*" and participants were asked to check a box to indicate whether they would prefer the small certain reward or large uncertain reward.

After completing the discounting assessment, the *BIS-11* was presented item (see appendix 1: 1.1 for reproduction). Participants were presented with 30 items and asked to rate how much each statement represented them from 1 (rarely/never) to 4 (almost always/always). This measure consists of three primary, and six secondary, subscales. The first, attention, assesses how well an individual can wilfully maintain their attention using statements such as "I concentrate easily" and "I squirm in lectures or plays". The second primary subscale, motor, examines whether an individual acts without thinking with items such as "I buy things 'on impulse'" and "I change jobs". Finally, the non-planning subscale measures how future oriented a person is, with items such as "I plan tasks carefully" and "I am more interested in the present than the future".

As described in the general methods, participants with an overall BIS score of 52-71 represent a "normal" level of impulsivity, scores lower than 52 indicate that the individual is either "overly controlled" and a score of 72+ indicates a "highly-impulsive" individual (Stanford et al., 2009).

7.2.3: Procedure:

The questionnaire offered a possible prize of £25 to anyone who completed the questionnaire in its entirety. The questionnaire was distributed via social media and on SONA (see general methods).

7.2.4: Classifications:

Participants were classified as a binger/non-binger based on responses to the question "On average, how many of units of alcohol do you consume per week?". Responses were split by thirds, those with the highest level of consumption were classed as *bingers* and those in the bottom third as *non-bingers*. The final third were designated "intermediates" (see general methods for more detail). Participants were also classified based on smoking status as *never smokers* (individuals who have never smoked a cigarette), *ex-smokers* (individuals who used to smoke but have now quit), *occasional smokers* (individuals who smoke up to 10 cigarettes a week) and *regular smokers* (individuals who smoke more than 11 cigarettes per week).

7.2.5: Calculating discounting functions:

For a full description of how discounting rates were derived for each questionnaire, see the general methods. Briefly, for both probability- and delay-discounting questionnaires, participant discounting functions were estimated by sorting the total items into subscales and then ordering these based on discounting rate at indifference. An individuals' discounting rate was then calculated by finding the geometric mean of the discounting rates at indifference for the last large (later or probabilistic) reward selection and the first small (sooner or certain) reward selection. For the sake of clarity, two examples will now be presented showing the first two items of the small reward subscale for both the delay- and probability-discounting questionnaires.

In the delay-discounting questionnaire, question 13 asks "would you prefer £34 today or £35 in 186 days?". The discounting rate at indifference for this question is 0.00016, meaning a participant with this discounting rate would be indifferent between those two rewards. This means that if an individual chooses the large reward we can infer that their discounting function is greater than 0.00016. Question 20 then asks "would you prefer £28 today or £30 in 179 days" and the discounting rate at indifference for this question is 0.0004. If the same person were to select the small option we can infer their discounting rate is between 0.00016 and 0.0004. The geometric mean between these two discounting rates, 0.00025, is used as an estimate of that individuals' delay-discounting rate (k).

In the probability-discounting questionnaire, question 1 "would you prefer £20 for certain or a 10% (1 in 10) chance of winning £80". An individual with a discounting rate of 0.33 would be indifferent between those two rewards, if we imagine a participant selected the large probabilistic reward for this question. Question 2 then asks "would you prefer £20 for certain or a 13% (1 in

8) chance of winning £80", giving this question a h at indifference of 0.45. Therefore, we can infer their discounting rate is between 0.33 and 0.45, giving this participant a discounting rate of 0.39.

Overall discounting rate was estimated by averaging the discounting rate for the 3 subscales. If a participant selected only large or only small rewards they were allocated the smallest or largest discounting function, respectively. If participant responses were inconsistent, they were excluded from the analysis.

For both probability- and delay-discounting measures the higher the estimation of discounting rate, k or h, the more rapidly the large reward has lost subjective value.

7.3: Results:

7.3.1: Data Analysis:

All *BIS-11* subscales were found to be significantly positively skewed, a square root transformation was applied. For the delay-discounting data set this corrected all apart from the secondary-subscale attention: (Z_{skew}= 2.49, p<.05).For probability-discounting, square root transformations corrected variables all apart from *non-planning*, which became slightly negatively skewed as a consequence (Z_{skew}= -2.56, p<.05). Overall, small, medium and large reward probability- and delay-discounting rates were non-normal and were log transformed, this correction did not eliminate deviations from normality but greatly reduced them. Uncorrected means and standard errors are reported. The association between impulsivity as measure by the BIS-11, discounting rate, smoking and binge status was assessed with multiple regressions.

7.3.2: delay-discounting questionnaire results

7.3.2.1: Participant characteristics:

There were 346 participants, aged 18-64 (M= 31.31, SE= 0.67) (see table 7.1A). When a median split is applied to age, 76.59% of participants were aged 18-39.

			Smokers	Age		Alcohol per week (units)		BIS-11 score	
		N	*N*	*M*	*SE*	*M*	*SE*	*M*	*SE*
A	*All participants*	346	127	31.31	0.67	9.09	0.66	65.21	0.53
	Females	226	80	31.81	0.57	6.07	0.53	65.56	0.67
	Males	119	47	32.84	1.02	14.94	1.51	64.56	0.85
B									
	Smoking status								
	Never Smoker	219	---	30.88	0.68	6.61	0.63	63.68	0.67
	Ex-smoker	---	63	35.59	1.41	12.56	1.92	65.89	0.99
	Occasional smoker	---	34	28.24	1.80	14.88	2.67	69.09	1.60
	Regular Smoker	---	30	34.67	1.81	13.30	2.83	70.60	1.88
	Binge classification								
	Non-Binger	120	29	31.68	0.96	1.68	0.47	63.87	0.91
	Intermediate	108	37	30.11	1.00	6.16	0.58	65.37	0.96
	Binger	118	61	33.48	0.97	19.40	1.35	66.42	0.86
	Medications								
	None	255	81	31.11	0.63	8.55	0.71	64.83	0.60
	non-psychoactive	58	33	35.24	1.52	12.09	2.19	65.84	1.34
	psychoactive	25	13	31.41	2.10	8.22	1.83	66.84	1.93
	BIS-11 classification								
	Highly-Impulsive	86	44	28.16	0.97	9.38	1.29	78.31	0.67
	Normal	242	82	32.96	0.69	9.46	0.82	61.88	0.33
	Overly-Controlled	18	1	33.72	2.41	2.78	0.88	47.44	0.98

Table 7.1 ***(A)*** participant information from all participants who completed the online delay discounting questionnaire including ns, average alcohol units per week and total *BIS-11* score, **(B)** participant information split by smoking status, binge and BIS classifications, and medication designations.

7.3.2.2: Discounting Rate:

Overall discounting rate was 0.019 (*SE:* 0.003), and, contrary to the finding by Kirby, Petry & Bickel (1999), this did not differ between males (*M*: 0.018, *SE*: 0.003) and females (*M*: 0.19, *SE*: 0.002). When split by reward size, there was a significant magnitude effect, F (1.80, 591.11) =333.77, $p<.001$, $\eta^2=.50$; participants discounted small ($M=.03$, $SE= 0.002$) rewards significantly faster than medium ($M=.02$, $SE= 0.001$, $p<.001$) and large rewards ($M=.01$, $SE= 0.001$, $p<.001$). There were no significant correlations between age, discounting rate and overall BIS score.

A hierarchical multiple regression was used to assess whether *BIS-11* subscales, overall BIS score, age and units of alcohol consumed per week could be used to predict overall discounting rate. Results revealed two significant predictors, the secondary subscales cognitive complexity and

motor, F (2,318) =6.64, p=.001; which could account for 40% of the variance in discounting rate.

The results of the regression revealed a positive relationship between discounting rate and cognitive complexity and motor subscales (see table 7.2). This means that the higher the score on the motor or cognitive complexity subscale the more rapid the discounting of rewards.

	b	***SE b***	***β***	***T test***
Step1				
constant	-2.82	.028		
cognitive complexity	.25	0.08	.17	t(319)=3.02, p=.003
Step 2				
constant	-3.23	0.34		
cognitive complexity	.18	0.09	.12	t(318)=2.07, p=.039
motor	.16	0.08	.12	t(318)=2.03, p=.043

Table 7.2: shows results of multiple regression with *BIS-11* primary and secondary subscales as predictors and overall discounting rate as dependent variable. Note: R^2=.03 for step 1: Δ R^2=.01 for step 2, *ps*<.01

Regressions were then used to assess whether smoking status (never, ex, occasional or regular smoker) or binge status (binger, intermediate, non-binger) could significantly predict overall BIS score or discounting rate.

Binge drinking shown to be a reliable predictor of overall BIS score. Results revealed that binge drinking was a significant predictor of BIS score, but intermediate drinking was not (see table 7.3).

	b	***SE b***	***β***	***T test***
Step1				
Constant: Non-Binger	7.97	0.06		
Intermediate	0.09	0.08	.07	t(343)=1.17, p=.242
Binger	0.16	0.08	.13	t(247)=2.08, p=.038

Table 7.3: shows results of multiple regression with binge status as predictors and *BIS-11* as the dependent variable. Note: R^2=.12 for step 1

Results revealed that smoking status could be used as a predictor of overall BIS score, F (3, 342) =7.15, p<.001; occasional smoking and regular smoking were significant predictors of BIS score, but being an ex-smoker was not (see table 7.4).

	b	*SE b*	*β*	*T test*
Step1				
Constant: never smoker	7.96	0.04		
Ex-smoker	1.47	0.08	.09	$t(342)=1.75$, $p=.082$
Occasional smoker	0.34	0.10	.17	$t(342)=3.12$, $p=.002$
Regular smoker	0.43	0.11	.20	$t(342)=3.71$, $p<.001$

Table 7.4: shows results of multiple regression with smoking status as predictors and *BIS-11* as the dependent variable. Note: $R^2=.05$ for step 1

7.3.3: probability- questionnaire results

7.3.3.1: Participant characteristics:

The 244 participants were aged 18-61 (see table 7.5). When a median split is applied to age, 89.33% of participants were aged 18-39. There were 87 smokers and 32 ex-smokers.

			Smokers	Age		Alcohol per week (units)		BIS-11 score	
		N	*N*	*M*	*SE*	*M*	*SE*	*M*	*SE*
A	*All participants*	244	87	23.32	8.69	9.39	0.64	67.68	0.55
	Females	173	56	22.43	0.66	8.16	0.62	67.29	0.84
	Males	71	31	25.38	1.03	12.96	1.61	68.58	1.19
B									
	Smoking status								
	Never Smoker	130	---	23.09	0.74	6.88	0.72	65.60	0.86
	Ex-smoker	---	32	28.53	2.35	8.56	1.84	66.34	2.00
	Occasional smoker	---	47	21.38	0.94	12.20	1.47	68.89	1.62
	Regular Smoker	---	40	22.18	0.85	15.18	2.06	74.13	1.70
	Binge classification								
	Non-Binger	85	13	23.75	0.88	0.84	0.12	63.60	1.15
	Intermediate	66	23	22.15	1.10	66.45	1.23	5.94	0.19
	Binger	99	51	23.72	0.91	71.99	1.02	19.22	0.97
	Medications								
	None	219	73	22.69	0.51	9.32	0.67	67.68	0.71
	non-psychoactive	16	7	31.00	4.01	9.47	2.63	64.06	3.21
	psychoactive	9	7	24.18	2.13	10.64	3.86	73.27	3.23
	BIS-11 classification								
	Highly-Impulsive	96	47	21.76	0.65	12.32	1.12	78.36	0.65
	Normal	136	35	24.01	0.81	8.10	0.83	62.78	0.46
	Overly-Controlled	18	5	26.50	2.77	3.56	0.87	47.67	0.64

Table 7.5 ***(A)*** participant information from all participants who completed the online delay discounting questionnaire including ns, average alcohol units per week and total *BIS-11* score, ***(B)*** participant information split by smoking status, binge and BIS classifications, and medication designations.

7.3.3.2: Discounting Rate:

There was a significant effect of reward size on discounting rate, F (1.80, 400.59) =5.50, p=.006, η^2=.02; participants discounted large rewards (M=3.47, SE= 0.30) significantly more than medium rewards (M=2.31, SE= 0.20, p=.017). Small rewards were discounted at a similar rate to large rewards (M=3.04, SE= 0.24) but significantly more than medium rewards (p<.001). Discounting large probabilistic rewards more rapidly than probabilistic medium rewards is consistent with the peanuts effect (Prelac & Loewenstein, 1991); however, that the small rewards were discounted at a similar rate to the large rewards is not.

Smokers (M=3.84, SE=4.16) had a significantly faster discounting rate for the small reward magnitude than non-smokers (M=2.68, SE=3.32), t (240) =-3.04, p=.003. There was no significant correlation between discounting rate, overall BIS score and age and no significant difference in discounting rate or overall BIS score between males and females. A multiple regression revealed that *BIS-11* subscales, overall BIS score, age and units of alcohol consumed per week could not be used to predict discounting rate for probabilistic rewards, there was however, a significant negative correlation between overall BIS score and age, r=-.19, p=.003.

Regressions were then used to assess whether smoking status (never, ex, occasional or regular smoker) or binge status (binger, intermediate, non-binger) could significantly discounting rate but neither could. However, binge drinking could be used to predict overall BIS score, F (2, 247) =16.10, p<.001. Results revealed that binge drinking was a significant predictor of BIS score, but being an intermediate drinker could not (see table 7.6).

	b	***SE b***	***β***	***T test***
Step1				
Constant: Non-Binger	7.95	0.07		
Intermediate	0.18	0.10	.12	t(247)=1.76, p=.080
Binger	0.52	0.09	.38	t(247)=5.57, p<.001

Table 7.6: shows results of multiple regression with binge status as predictors and *BIS-11* as the dependent variable. Note: R^2=.12 for step 1

The only significant model was smoking status and overall BIS score, F (3, 246) =6.86, p<.001. Results revealed that regular smoking was a significant predictor of BIS score, but being an occasional or ex-smoker was not (see table 7.7).

	b	*SE b*	*β*	*T test*
Step1				
Constant: never smoker	8.08	0.06		
Ex-smoker	0.04	0.13	.02	$t(246)=0.32$, $p=.752$
Occasional smoker	0.18	0.11	.12	$t(246)=1.81$, $p=.072$
Regular smoker	0.51	0.12	.28	$t(246)=4.41$, $p<.001$

Table 7.7: shows results of multiple regression with smoking status as predictors and *BIS-11* as the dependent variable. Note: $R^2=.08$ for step 1

7.4: Discussion

These two internet questionnaires sought to examine the relationship between discount rate for delayed or probabilistic rewards and trait impulsivity levels within a large non-clinical population whilst exploring the factors of smoking status, drinking behaviour, age and gender.

Results supported previous research that reward magnitude has a significant effect on discounting rate. For delay-discounting, small rewards were discounted more rapidly large (magnitude effect). For probability discounting, though large rewards were discounted more rapidly than medium rewards (peanut effect) the small rewards were discounted at a similar rate to large rewards. This converse effect of reward size on discounting rate has previously been taken as evidence that probability- and delay-discounting reflect related but distinct processes (Myerson, Green, Hanson, Holt & Estle, 2003).
The effect of reward size was more robust for delay than probability discounting measures; small rewards were consistently discounted more rapidly when delayed than large rewards, whereas, discounting rate for small and large probabilistic rewards were similar.

The current investigation found several interesting dissociations between probability- and delay-discounting. In accordance with previous findings, the results of these questionnaires showed a positive correlation between overall *BIS-11* score and delay, but not probability, discounting rate (Reynolds et al., 2007; Mitchell, 1999); supporting the assertion that discounting of probabilistic and delayed rewards are discrete. In accordance with existing literature, two subscales, motor and cognitive-complexity, were found to positively correlate with delay-discounting rate, (Petry, 2001c; Eisenberg et al., 2007; Kirby & Petry, 2004; de Wit et al., 2007). The motor subscale is characterised by items such as "I act 'on impulse'", "I act on the spur of the moment" and reflects an inability to withhold an action and or propensity to act without forethought (Patton et al.,

1995). This finding suggests that the reason individuals discount delayed rewards rapidly is due to an inability to withstand delay or withhold a response, meaning that opting for the immediate, smaller option over the larger-later option is the result of an impaired ability to control one's behaviour. This supports the assertion that the rate at which one discounts delayed rewards is a metric of self-control (Weatherly et al., 2014).

The subscale, cognitive complexity, consists of items such as "I like to think about complex problems" (reverse scored) and "I get easily bored when solving thought problems". This subscale loads onto the non-planning primary subscale, which measures how individuals consider the long term implications of their choices (Patton et al., 1995) and presumably, one's ability to consider the *possible* consequences of one's actions. Such an interpretation is, in essence, the same as some definitions of discounting as a relative insensitivity to behavioural consequences (Krishnan-Sarin et al., 2007; Moeller, Barratt, Dougherty, Schmitz & Swann, 2001). Therefore, the results of this investigation suggest that when individuals discount delayed rewards rapidly they do so due to an inability to withhold their actions and, even if they do restrain their motor response, a fail to consider the repercussions of their choice.

Within the current investigation the *BIS-11* revealed no significant predictors of probability-discounting; however, impulsivity is a multidimensional construct, which has not yet been fully characterised by a single or combination of measures (Caswell, 2013). Trait impulsivity may well encompass the inability to withstand delay before reward receipt (Ainslie, 2012) or risk seeking behaviours (Steel & Blaszczynski, 1998) or a combination of the two (Shead & Hodgins, 2009). For this reason, the failure to find a relationship between probability-discounting and the *BIS-11* is more likely to reflect limitations of the measures used rather than a lack of association altogether.

In the past, accounts of probability-discounting have attempted to interpret results in terms of delay-discounting and *vice versa*; for example, delayed rewards could be thought of as probabilistic in that as time progresses reward receipt becomes less likely (Green & Myerson, 1996) or that repeated attempts to acquire an unlikely reward would take time, meaning ultimate reward receipt would be delayed (Rachlin, Logue, Gibbon, & Frankel, 1986). More recently delay-discounting has been thought of as measuring self-control or impulsivity, whereas probability-discounting has been defined as a measure of risk seeking or aversion (Weatherly et al., 2014). Further to this, results from studies examining the correlation between probability- and delay-discounting have proven largely inconsistent. Shead and Hodgins (2009) found a negative

correlation between probability- and delay-discounting, meaning those who were delay averse were also be risk-seeking whereas Richards et al. (1999) and Myerson, et al. (2003) showed the opposite. Useful future experiments would use a variety if impulsivity assessments in conjunction with the *BIS-11* to investigate the relation between probability-discounting and impulsivity in more detail.

The results of both the probability- and delay-discounting questionnaires supported previous research showing that smokers discount both real and hypothetical rewards more rapidly than non-smokers (Amlung & McKillop, 2014; Baker et al., 2003; Reynolds, 2004; Odum, Madden, & Bickel, 2002; Yoon et al., 2007; Reynolds et al., 2004). Furthermore, when smokers were split into groups, smoking regularly (probability and delay discounting questionnaires) and smoking occasionally (delay discounting questionnaire) could significantly predict overall BIS score. However, the current questionnaires only asked participants whether they smoked "between 1 and 10 cigarettes per day" or "11 and 20 per day etc" so no further investigation into the correlational relationship between discounting rate and smoking 'severity' could be conducted. An area for further investigation might be to assess whether heavy smokers discounted rewards more rapidly than 'social smokers'.

Acute exposure to alcohol has been shown to significantly affect probability- but not delay-discounting rate (Bidwell et al., 2013) and heavy drinking is related to rapidly discounted rewards (Field et al., 2007). Furthermore, Binge drinking has been shown to increase impulsive responding in the Iowa gambling task (Goudriaan, Grekin, & Sher, 2007). However, results from the current study showed no significant correlation between alcohol units consumed per week and discounting of delayed or probabilistic rewards, though this result is not unprecedented (Fernie et al., 2010).

In support of previous research (Papachristou et al., 2012), binge drinking was found to be a significant predictor of overall BIS score in both the probability and delay questionnaires. However, there was no difference in discounting rate between bingers and non-bingers for delayed or probabilistic rewards. There are a couple of potential explanations for this, the first being that previous studies examining the effect of alcohol consumption on discounting rate have used alcoholics (Petry, 2001a) or "problem drinkers" (Vuchinich & Simpson, 1998) whereas the current samples were non-clinical. In addition to this, the method of assessing discounting consisted of 27 or 30 items, whereas previous methodologies have been substantially longer

(Richards et al., 1999). This means that the estimation of discounting rate in these alternative methodologies may have been more sensitive than the current protocol.

Contrary to previous research this study found no evidence of sex differences in discounting rate for either delayed or probabilistic rewards (Kirby & MarakoviĆ, 1996). The results of these questionnaires also showed no significant correlation between age and discounting rate, which was again in disagreement with existing evidence (Olson et al., 2007; Green et al., 1994; 1996a; 1999b). A possible explanation for this is that, though this questionnaire was presented online with the aim of reaching as many participants as possible, exposure appears to have been restricted to a particular age group. The questionnaires were distributed predominantly via social media, which is used significantly more by younger adults (Holt, Shehata, Strömbäck, & Ljungberg, 2013). In both questionnaire samples, participants aged 18-30 made up more than half of the sample. As previous research has shown that questionnaire responses online and on pen-and-paper do not significantly differ (Gosling et al., 2004; Smith & Hantula, 2008), future investigations could use a combination of internet and hardcopy distribution, or use internet platforms targeted at older adults in addition to social media. Further to this, the current investigation aimed to assess impulsivity however, completion of the questionnaire was time consuming. Previous research has shown that drop-out rates of online questionnaires are high so it is possible that the very sample population we were aiming to examine did not complete the entire assessment (O'Neil, Penrod, & Bornstein, 2003). By extending the procedure to include pen and paper distribution, in addition to internet recruitment, future assessments may be able to avoid this difficulty.

Chapter 7: online questionnaires

- An online questionnaire assessing delay-discounting and trait impulsivity (as measured by the BIS-11) found a significant correlation between discounting rate and overall BIS-11, motor and cognitive complexity subscales
- An separate online questionnaire assessing probability-discounting and trait impulsivity showed no significant correlations between discounting rate and BIS-11 scores
- Both online questionnaires replicated previous research in finding a significant effect of reward size, meaning that small delayed rewards were discounted more rapidly than large delayed rewards (magnitude effect) and large probabilistic rewards lost value faster than small probabilistic rewards (peanuts effect).
- Smokers discounted probabilistic and delayed rewards more rapidly than non-smokers
- There was no relation between delay- and probability-discounting rate alcohol use and age
- Binge-drinking and smoking occasionally or regularly were found to be predictors of overall BIS score, whereas intermediate or non-binging and ex- and never-smoking were not.

8. General Discussion

8.1: Theoretical background

Positive utility can best be described in terms of the subjective experience of reward (experienced utility), the active reconstruction of previous experiences (remembered utility), the anticipated value of the reward (predicted utility) and, finally, the potential value of the outcome at the point of making a decision (decision utility) (Kahneman, Wakker & Sarin, 1997; Berridge & O'Doherty, 2014; Berridge & Alridge, 2008). The combination of these utilities represent the overall positive value of a reward, meaning that overall utility can change with experience and be increased if rewards are available absolutely (certainty effect; Tversky & Kahneman, 1981) and without delay (immediacy effect; Keren & Roelofsma, 1995). According to rational choice theory, "rational" decisions are consistent and represent instances where experienced reward utility is maximized (Ainslie, 2012).

In this thesis, I sought to examine economically and hedonistically "irrational" behaviour. The former pertains to inconsistent choices, wherein there is a reversal of preferences as the result of increased risk (Green & Myerson, 2004) or delay (Slovic & Lichtenstein, 1971). The latter refers to making a decision based on what one *wants* most but does not necessarily *like* best. Such instances can be accounted for by the incentive salience model, which posits that wanting and liking are distinct and that imbalances between these motivational and hedonic drives leads to maladaptive behaviours, such as drug addiction (Robinson & Berridge, 1993; Berridge & Robinson, 1998). Both these hedonistic and economic deviations from rationality represent instances where decision utility exceeds the predicted or experienced utility (decision utility > predicted utility; decision utility > expected utility) (Berridge & O'Doherty, 2014). In the first instance, this occurs because the subjective cost (such as increased delay or reduced probability of reward receipt) associated with the outcome lowers the predicted utility, leading to a preference reversal. Whereas hedonistically irrational decisions occur due to reward or reward-paired cue being 'wanted' (decision utility) more than it is liked (experienced utility) (Berridge & O'Doherty, 2014).

As a central aim of the work outlined in this thesis was to develop translational models and procedures for examining decision-making and motivated action under conditions of uncertainty

and/or delay, before turning to the results and their interpretation(s), I will first discuss the need for such approaches.

8.2 Translational models

The substantial commonality in the neural networks underlying goal-directed behaviour in mammals, including between rodents and humans (Balleine & O'Doherty, 2010), has meant that non-human animal models are extensively used to examine the psychological and neural mechanisms of a wide variety of behaviours and cognitive processes, including attention, memory or decision-making (Keeler & Robbins, 2011). There are nonetheless a limited number of attempts in the extant literature to develop analogous tasks for exploring motivation in both human and non-human subjects (Balleine & O'Doherty, 2010). As dysregulation of Pavlovian and/or instrumental learning processes is hypothesized to contribute to the aetiology of a range of neuropsychiatric disorders such as drug-addiction, depression and schizophrenia (Keeler & Robbins, 2011; Murray et al., 2008; Corlett et al., 2007; Gradin et al., 2011), the importance for standardization of methods and procedures, between and within laboratories as well as species, is self-evident.

Indeed, the aetiology of "irrational" decision-making is likely complex and for the moment remains poorly understood at a mechanistic level. For instance, the contribution of individual (personality) differences, such as impulsivity, may be partially the result of genetic influences, of experiential (learning) factors, or a combination of the two (Potenza, 2009). In addition, exposure to drugs (including drugs of abuse such as cocaine or heroin) may alter the neural structures (and/or function) that underpin decision-making though how this occurs remains largely unknown. Whilst the chronic administration of such drugs is rarely feasible in non-clinical and/or drug naïve human subjects, the use of non-human animal models allows for examination of drug effects over extended periods and/or over a wide range of doses (Ator & Griffiths, 2003). For these reasons, animal models provide necessary and invaluable insights into the development and maintenance of aberrant behaviours to inform potential interventions. However, for successful translation between human and non-human animal research to occur, it is essential that the tasks used to examine such behaviour are as analogous as possible. Furthermore, because few (if any) animal models provide researchers an unambiguous view into the affective state of the subject (Stephens et al., 2010) the use of back-translational (human to non-human animal) models is likewise essential and a critical means to examine the validity of non-human animal models, the empirical results and insights that these yield (Keeler & Robbins, 2011). For these reasons, the

design and execution of the experiments presented in my thesis have sought a cross-species translational approach wherever possible.

8.3.: Procedural aspects:

Studies of delay-discounting using non-human animals suggests a phylogenetic gap between humans and other animals, with the latter deemed to be more impulsive or present-orientated than ourselves (Rosati, Stevens, Hare & Hauser 2007). This has been attributed to a number of factors such as the size and cytoarchitectural features of frontal lobe regions (McClure, Laibson, Loewenstein, & Cohen, 2004), metabolic rate (Tobin & Logue, 1994) as well as basic time perception (Roberts, 2002). The question remains, how comparable monetary price lists (e.g. Kirby, Petry & Bickel (1999); Madden, Petry & Johnson's (2009)), the most commonly used method of measuring discount rates in human participants, and animal behavioural tasks are. These questionnaires are widely used due to the fact they are easy to administer and interpret, and they allow for examination of extreme delays or rewards. However, selecting between two imaginary outcomes to be received at two imaginary delays is quite distinct from genuine rewards and experienced delays (Odum, 2011). Indeed, when using a food delay-discounting task, humans typically display a similar level of patience as chimpanzees and bonobos but, in the same study, humans were more willing to wait for money than food; this suggests that the comparative patience shown by humans in discounting tasks is, at least in part, a product of the mode of assessment. Furthermore, compared to questionnaire assessment of discounting, experiential tasks have been shown to produce more impulsive choices (Reynolds, 2006).

In this thesis I therefore presented an alternative to the experiential discounting task (EDT; Reynolds & Schiffbauer, 2004), which was specifically designed to be comparable to the paradigms used in the animal model. Firstly, unlike the EDT and similar to typical rodent paradigms, the task duration and trial number were fixed thereby preventing participants from always selecting the small reward (local minimization) in order to earn more rewards overall, by completing more trials in a session (global maximization), or to and end the task more rapidly. In addition, the probability of receiving any reward during a trial of the EDT, irrespective of option selection, is 35%; this probabilistic component was also removed from the program used in the current experiments. The reason for this, is that when the probabilistic component is included in the task, the effect of delay on discounting behaviour cannot be isolated. The inclusion of a probabilistic component into delay-discounting tasks significantly affects discounting rates; though interestingly, adding delays to probabilistic outcome decisions made no difference to discounting

rates (Weatherly, Petros, Jónsdóttir, Derenne & Miller, 2014). In addition, previously participants have exploited the probabilistic component by repeatedly selecting the probabilistic large-reward in order to drive-up the adjusting small-reward value (Smits et al., 2013). The tasks used in chapter 6 of this thesis were designed to address these differences.

8.4: Aims of this thesis:

The specific aims of the present thesis were the following: Firstly, to explore and compare across species (human, rat and mouse) hedonistically and economically irrational decision making under controlled laboratory conditions. Secondly and to this end, to develop comparable translational behavioural tasks for studying such decision making processes; these aims were addressed in chapters 1-4 all of which involved behavioural tasks completed using a human or non-human animal model. In doing so, the third aim was to examine the effects of devaluation, reward-contingency and delay before reward receipt on utility of reward in both discounting and autoshaping paradigms; this was assessed in chapters 3-5. The fourth aim was to examine whether autoshaping paradigms utilising multiple cues produce the same proportions of sign- and goal-trackers and to assess whether such procedures are comparable; this was examined in rodents in Chapter 3 using multiple levers, and in Chapter 4 using multiple cue images in human participants. The fifth and final aim was to explore how individual differences, such as drinking behaviour, drug experience and/or state/trait impulsivity level, interact with devaluation to influence economically and hedonistically "irrational" decisions; which was considered in chapters 6, 7 and 8.

8.5.: Hedonistically irrational decisions

8.5.1: Contingency

Previous research using non-human animals has shown that reward uncertainty leads to a more pronounced manifestation of sign-tracking (Anselme, Robinson & Berridge, 2012; Boakes, 1977), but not of goal-tracking responses. Chapter 3's results were broadly in accordance with this earlier literature, in showing that lowering reward contingency increased total response rates and potentiated sign-directed responses. In the animal model (presented in Chapter 3), goal-directed responses were positively correlated with the probability of reward receipt. These results were not entirely unexpected as previous research has shown that sign-tracking responses are more inflexible than goal-tracking responses (Tomie, 1996). The effect of contingency had a less

consistent effect on human sign-tracking (Chapter 4); in experiment 1, lower reward contingencies produced higher goal-directed behaviours and higher reward contingencies produced greater sign-directed behaviours. In experiment 3 of chapter 3, reward contingency was positively correlated with goal-directed and negatively correlated with sign-directed responses. A possible explanation for this is that the increased complexity of the screen in experiment 3 gave the participants more information to attend to. This alteration in stimuli presentation in experiment 3 (compared to experiment 1, see figure 4.26) also had an effect on responder type, increasing the number of goal-trackers relative to sign-trackers, which was attributed to the increased contextual cues.

8.5.2: Devaluation

The effect of devaluation on sign- and goal-tracking behaviour was examined in chapter 3; pre-exposure to either food or sugar pellets induced a non-specific devaluation effect, and while both goal- and sign-tracking responses were reduced, goal-tracking responses were more affected than sign-directed responses. Goal-directed (action-outcome) behaviour is distinctly different from habitual (stimulus-response) behaviour in that it is deliberate and requires a certain level of understanding (Pezzulo, van der Meer, Lansink & Pennartz, 2014). In addition to this, where, in habitual behaviour, the presence of a reinforcer stands to influence the relationship between a stimulus and conditioned response, goal directed behaviour is carried out in order to acquire the reinforcer (Everitt & Robbins, 2005). This means that goal directed behaviour is sensitive to devaluation either intrinsically or contextually (Doya, 2008). This distinction is important, as it means that, for goal-directed behaviour, the reward is a hedonic motivator (Kelley & Everitt, 2002). The fact that the devaluation manipulation led to a reduction in all responding, but goal-directed in particular, means the observed behaviour was indeed sign- and goal-tracking rather than behaviour produced by over-training. Furthermore, this result supports the assertion in section 7.5.1, that goal-directed responding is more sensitive to changes in value than sign-directed.

8.5.3: Impulsivity

It has been suggested that autoshaping conditioned responses are attributable to intrinsic factors such as impulsivity (Tomie et al., 1998). As experiments examining sign- and goal-tracking in humans are rare (and at the time, analogous tasks were non-existent), any specific predictions

regarding the association between sign-and goal-tracking responses were based entirely on the non-human animal literature. Measures of impulsive action and choice are uncorrelated in humans and rat models (Broos et al., 2012). Sign-trackers have been shown to be more impulsive than goal-trackers in measures of impulsive action, but not impulsive choice (Lovic et al., 2011). Similarly, Flagel et al. (2010) compared performance on impulsive action and choice tasks in rats selectively bred for high or low locomotor responsiveness to novelty, showing that high-responders were significantly more likely to develop into sign-trackers and are significantly more impulsive in measures of impulsive action than low responder rats. However, the latter were significantly more impulsive in measures of impulsive choice than high-responders. However, contrary to this, in chapter 4 we found no association between Pavlovian conditioned gaze (PCG) classification (intermediate, sign- or goal-tracker) and impulsive choice (delay-discounting). An explanation for this might be the obvious species difference. Alternatively, the reward used in the impulsive choice measure in chapter 4 was hypothetical money, whereas the rats in Flegel et al.'s (2010) experiment were responding for food pellets, so the differing result might be due to the difference in reinforcer type and the motivational processes they rouse. In addition, chapter 4 also revealed no association between trait impulsivity level, drug use or alcohol use and PCG classifications, therefore, an alternative reason for this is the small ns within each classification. In order to assess the relationship between impulsive choice and action and alcohol and drug use more accurately, further future experiments would need to either pre-screen sign- and goal-trackers or BIS-11 classifications at the outset.

8.5.4: Implications for hedonistically irrational decisions

According to incentive motivation theory, incentive salience associated with a reward can become generalized to environmental cues (Flagel, Akil & Robinson, 2009). Substantial evidence has shown that exposure to these reward paired cues contributes substantially to compulsive behaviours and, in the case of substance abuse, relapse (Everitt & Robbins, 2005; Corbit & Janak, 2007). This can occur in two ways, firstly, neurobiological pathways, rendered sensitized by drug use, are now activated by these previously innocuous stimuli; meaning the cues alone can induce drug-craving (Bevins & Palmatier, 2004). Alternatively, the cues themselves can be attributed with incentive salience, which can induce 'wanting' but also can cause the stimulus itself to become attractive (Berridge, 2012). Critically, attribution of this incentive salience has been shown to be subject to individual differences with sign-trackers attributing it to the reward paired

stimuli (Davey, Cleland & Oakley, 1982), and goal-trackers to the site of goal delivery (Boakes, 1977).

As previously discussed, hedonistic irrationality occurs due to elevated decision utility diverging from, and surpassing, predicted and experienced utility, meaning individuals may 'want' what they cognitively desire to avoid, do not expect to like or have disliked in the past (Berridge & Aldridge, 2008). The 'causes' for this divergence are twofold: first, physiological changes related to drug-experience dependent sensitization of the mesolimbic system. Second, psychological factors, such exposure to a discrete cue or context previously paired with the reward, prompting a transient shift in utilities. When exposed to a cue or context imbued with incentive salience, this can cause a transient rise in decision utility that exceeds either predicted or experienced utility, particularly if the individual has a sensitized mesolimbic system, inducing "wanting' (Berridge & Aldridge, 2008).

As shown in chapter 3, sign- and goal-tracking responses are differentially effected by reward devaluation. Pre-exposure to the reward before test produced non-specific reduction in responding which was more marked in goal-, as opposed to sign-, directed behaviours. Analysis of the proportions of responses also revealed that propensity to produce sign-tracking responses increased with pre-exposure to rewards. This effect was also demonstrated by Morrison, Bamkole & Nicola (2015); pre-exposure to a sucrose reward proportionally heightened sign-tracking responding but diminished goal-tracking. Combined these results are in accordance with earlier suggestions that the sign-tracking topography is more reflexive than goal-tracking (Tomie, 1996).

Interestingly, the influence of discrete and contextual cues has been shown to differentially effect autoshaping response groups, with sign-trackers being more influenced by distinct stimuli whereas goal-trackers are more effected by contextual cues (Robinson, Yager, Cogan & Saunders, 2014). This has led some to suggest that the formation of the goal-tracking response is more complex as it relies on the acquisition of spatial information (Clark, Hollon, & Phillips, 2012).

It has been suggested that the propensity to sign-track is a behavioural marker for proclivity towards addiction (Tunstall & Kearns, 2014). Sign-tracking rodents engage in a higher level of risk-taking behaviour (Olshavsky et al., 2015) and are more likely to self-administer cocaine (Beckmann, Marusich, Gipson & Bardo, 2011) and alcohol (Anderson & Spear, 2011) than goal-trackers. Furthermore, presentation of a cue (retractable lever) previously paired with a drug

reward (e.g. cocaine (Yager & Flagel, 2013) or heroin (Peters & De Vries, 2014)) elicits approach and vigorous responses from sign-trackers but not goal-trackers. Alternatively, Garofalo, & di Pellegrino (2015) have suggested that sign- and goal-tracking represent the susceptibility of individuals to assign value to discrete or contextual cues. In support of this, cocaine paired contextual cues have been shown to induce heightened conditioned hyperactivity in goal-trackers compared to sign-trackers (Saunders, O'Donnell, Aurbach, & Robinson, 2014). This finding led to the suggestion that individuals are selectively sensitive to particular "triggers of relapse" (Saunders et al., 2014. p.456).

Conditioned response topographies may have arisen from individuals adapting to particular scenarios; goal-trackers to environments where there is little danger and time for consideration and sign-trackers to more dangerous circumstances, when rapid decision making might be necessary (Morrow, Saunders, Maren, & Robinson, 2015). Boakes (1977) suggested that these systems act in competition, so a tendency to sign-track is negatively correlated with an inclination to goal-track. As the proportion of sign-trackers and the intensity of sign-tracking responses is negatively correlated with reward contingency (chapter 3; Anselme, Robinson, & Berridge, 2013), whereas the reverse is true of goal-tracking (Anselme, 2015), it has been suggested that only intermediate responders and sign-trackers experience competition between goal and cue directed responding, whereas goal-trackers are "consolidating a natural trend" (Anselme, 2015, p.8). There is some evidence to support this, as the sign-tracking response is acquired through learning (Flagel, Akil & Robinson, 2009), whereas a tendency to goal-track is observable in all subjects from the outset of training.

There have been several recent attempts, including one described in this thesis (see chapter 4) to model sign- and goal-tracking behaviour in humans, most often by measuring visual attention and eye-movements. The first of these by Le Pelley, Pearson, Griffiths & Beesley (2015), demonstrated that a distracting visual stimulus, the colour of which had been paired with high or low reward, could capture and draw attention away from the goal; even when doing so lowered the overall reinforcement rate. In another, electroencephalography-based, study comparing reactivity to pleasant food cues, sign-trackers were more reactive to food cues, but less reactive to control images, than goal-trackers (Versace, Kypriotakis, Basen-Engquist & Schembre, 2015). The same study further compared difference in sign- and goal-tracking propensity in average weight and obese individuals; the proportion of over-and normal weight participants was evenly distributed across sign- and goal- trackers so the authors attributed the propensity to sign-track

with "impulsivity, affect regulation expectancies, genetics or the environment" (Versace et al., 2015, p.6). Finally, recently Garofalo & di Pellegrino (2015) examined sign- and goal-tracking using a Pavlovian-Instrumental-Transfer (PIT) task and were able to discriminate between conditioned response topographies based on dwell time. Unlike results presented in chapter 3, Garofalo & di Pellegrino (2015) found a significant difference in BIS-11 impulsivity levels across conditioned response groups. A potential explanation for why the results of chapter 3 did not replicate this is due to the complexity of the task I used to assess sign- and goal-tracking behaviour compared to Garofalo & di Pellegrino (2015).

8.6.: Economically irrational decisions

8.6.1.: Contingency

The effect of contingency on discounting was explored in chapters 5, 6 and 7. In chapter 5 I presented a novel paradigm, which successfully demonstrated probability-discounting in mice. Across training, subjects were shown to be sensitive to two incremental changes in reward probability. Interestingly, the same subjects were also trained on a delay-discounting paradigm but this type of responding was acquired substantially faster than probability-discounting. In addition to this, probability-, but not delay-, discounting was shown to be sensitive to reward devaluation. In chapter 6, I presented the results of the same paradigm when administered in human participants and showed there was a significant effect of devaluation on probability-discounting alone, but only in highly impulsive participants. In conjunction, these results suggest that delay-discounting is more robust than probability-discounting. Finally, in section 2 of chapter 7, different to delay-discounting rates, probability-discounting was ubiquitous across smoking and drinking classifications, and uncorrelated with BIS-11 score. These results suggest that though probability and delay can both be conceptualised as costs, lowering subjective utility, they reflect separate, though related, processes of devaluation.

8.6.2: Devaluation

In chapter 6, a training game was used to devalue the rewarding points animation. The influence of this manipulation was inconsistent across individuals, experiments and discounting paradigms. For the probability-discounting paradigm the devaluation suppressed responding in the highly-impulsive participants. Conversely, only overly-controlled participants were affected by the devaluation manipulation for delay-discounting but its influence differed across experiments,

suppressing discounting in one but potentiating it in the second. One possible explanation for this is the priming manipulation, which was conducted only in the third experiment in the chapter and may have influenced the effectiveness of the devaluation.

8.6.3.: Impulsivity

A preference reversal refers to when an individual switches their choice, for instance, as a function of external factors, such as effort. When selecting between a small and a large reward, an agent might switch from selecting the large-reward to the small-reward because the increasing delay before, or decreasing probability of, large reward receipt (for more detail see general introduction). Such behaviour has been termed "impatient" (Kacelnik, 2003), "short-sighted" (Stephens & Anderson, 2001) or lacking in self-control (Mazur & Logue, 1978; Rachlin, Brown, & Cross, 2000).

It has been suggested that both probability- (Yi, Mitchell & Bickel, 2010) and delay-discounting (Bickel & Marsch, 2001; MacKillop et al., 2011) are measures of impulsivity. According to this view, impulsive responding in probability-discounting is a preoccupation with potential reward size, rather than the probability of reward receipt (Shead & Hodgins, 2009). Put another way, gamblers focus more on how much they stand to win, rather than the likelihood of actually winning. Whereas, for delay-discounting, impulsive people are delay averse, meaning they discount delayed rewards more rapidly than controls (see Perry & Carroll, 2008 for review). In this series, impulsivity levels were assessed using the BIS-11 but no relation between BIS-11 score and discounting rate was observed in chapters 4, 6 or section 2 of Chapter 7 (probability discounting). In section 1 of chapter 7, results revealed a significant correlation between delay-discounting rate and overall BIS-11, motor and cognitive complexity subscales a finding that has been replicated elsewhere (Petry, 2001c; Eisenberg et al., 2007; Kirby & Petry, 2004; de Wit et al., 2007). The failure to find an association between probability discounting measures and BIS-11 lends support to the increasing body of evidence that discounting of probabilistic and delayed rewards are mediated by dissociable mechanisms (see st Onge & Floresco, 2009 for a review, and section 8.7).

An issue to be addressed is why the SDDCT in chapter 6 did not replicate the finding in chapter 7 of an association between discounting rate and overall BIS-11 score. A possible explanation for this is that the delays used by the SDDCT and the Kirby, Petry and Bickel (1999) questionnaire are extremely different; with the longest delay in the SDDCT being 64 seconds and the equivalent from the Kirby, Petry and Bickel (1999) being 186 days. In support of this, research examining

the relationship between the EDT (Reynolds & Schiffbauer, 2004), which uses similar delays to the SDDCT, failed to find any correlation between discounting rate and overall BIS-11 score (Krishnan-Sarin et al., 2007; Peters, Petry, LaPaglia, Reynolds, & Carroll, 2013; Reynolds, Ricahrds & de Wit, 2006).

8.6.4: Implications for economically irrational decisions

Some have argued that preference reversals arise as consequence of economic understanding because financial literacy, and willingness to engage in such education, is associated with reduced selection of the small reward over the large reward in a delay-discounting task (Meier & Sprenger, 2013). Furthermore, discounting rates are influenced by interest rates, therefore it has been argued that researchers need to take nominal interest rates into account when studying discounting rate (Kawashima, 2006). Similarly, discounting rate has been shown to be influenced by inflation: Ostaszewski, Green &Myerson (1998) compared discounting rate in Poland during the early 90s for US dollars and Polish zlotys. The results show that the less stable currency, the zloty, depreciated in value significantly faster than the dollar. However, factors such as interest rates and inflation cannot be influencing decisions across time spans as short as minutes or seconds, as has been shown (Jimura, Myerson, Hilgard, Braver, & Green 2009). In addition, the observed discounting rates far exceed that which one would expect based entirely on economic justifications (Frederick, Loewenstein, & O'Donoghue, 2002). Furthermore, if discounting occurred purely as a result of economic influences then discounting should not occur for primary reinforcers such as food, which is not the case (Rasmussen, Lawyer, & Reilly, 2010; Hendrickson & Rasmussen, 2013; Odum, Baumann & Rimington, 2006) or alternative secondary reinforcers such as points (as shown in Chapter 6). As pointed out by Angott (2010), in an evolutionary process preserving adaptive, advantageous behaviours, how can discounting continue to exist if it does not incur some benefit? This has led to the suggestion that such a trait may have imbibed a certain evolutionary advantage (Winstanley, Olausson, Taylor & Jentsch, 2010) as the ability to react quickly to changing circumstances or events is a positive attribute in a number of circumstances (Dalley, Everitt & Robbins, 2011)

Hammerstein (1998) makes the comparison between Charles Darwin's *Origin of Species* (1859/2004) and Adam Smith's *The Wealth of Nations (*1776); likening "struggle for existence" (p.59) underpinning Darwin's theory of natural selection to competition as an essential, driving-force for economic success. Despite this similarity in the very fundamentals of both evolutionary biology and economics, an intellectual interaction between these two, seemingly disparate, areas

of study did not really begin until after the publication of von Neumann and Morgenstern's (1944, as cited in von Neumann & Morgenstern, 2007) *Theory of Games and Economic Behavior.* The subsequent application of game theory to natural selection altered our understanding of the evolution of a new trait; prior to this, many biologists had held the view that such traits would develop, and need to be explained, in terms of how beneficial it might be to the continuation of the species; rather than how that trait may benefit the individual alone (Smith, 1976). This understanding, that both evolution and the theory of games reflect a kind of individualism, allowed for the examination of natural selection in new terms, not just for populations or even groups, but for individuals.

Evolutionary mechanisms have produced strong selective pressures for animals to discount future reinforcers (Stevens & Hauser, 2004); an example of this might be, if an animal were to come across an unripe piece of fruit; the choice being either to wait for it to ripen or consume it immediately- waiting increases the chance of another animal eating it but also would increase the quality of the reward (i.e. by the increase in sugar seen in ripening). From this standpoint, delay-discounting may have manifested prior to probability-discounting and understanding of the latter arisen from the former. Results from discounting experiments have previously shown that discounting rates appear to be explicitly linked, in that participants report feeling that the probability of receiving a reward decreases as the delay increases (Patak & Reynolds, 2007).

An alternative account of the origins of discounting behaviour suggests that when making a decision an individual attempts to take into account the consequences of the selection they are opting for but also of the alternative, non-chosen option (Bertoux et al., 2014). This action allows for the comparison of what has been and what might have been, and when the comparison is unfavourable it produces the cognitive emotion known as regret (Canessa et al., 2009). However, preference reversals occur as a result of an intrapersonal empathy gap between our current self and our future selves; at the point of decision making we fail to appreciate the subjective or visceral experience we are committing our future selves to (Loewenstein, Prelec & Shatto, 1998). In order to examine the relationship between regret and preference reversals, Bertoux et al. (2014) compared patients with behavioural frontotemporal dementia, Alzheimer's disease and matched controls and found those with behavioural frontotemporal dementia showed consistency in their responses and a reduction in preference reversals, compared to other participants. However, when asked questions about their decisions after the test, patients expressed regret after the fact. This led to Bertoux et al. to suggest that this group was failing to accurately

anticipate their sense of regret, but leaving their sense of the emotion intact. In chapter 6, mood ratings were taken before and after the completion of the discounting programs, however, analysis revealed no significant change in any of the emotions examined. However, a key difference in the assessment of mood by Bertoux and that used in chapter 6, is that the mood Bertoux was assessing was induced by the decisions the participants made, whereas the moods analysed in this thesis referred to those prompted by the completion of the discounting task itself.

Bertoux's assertion supports yet a different, though related account of discounting; that decisions are made on the basis of anticipated emotions (Loewenstein, Weber, Hsee & Welch, 2001). In this way, positive events might be negatively discounted in order to "extend the otherwise fleeting benefit provided by consumption" (Loewenstein, 1987; p. 672). For example, participants were willing to pay more for a kiss from a movie star in 3 days rather than immediately (Loewenstein, 1987). This experience of anticipation might account for why delay-discounting was more robust to changes in reward utility than probability discounting in chapters 5 and 6. As selecting the large-variable reward in probability discounting risks all potential experienced utility, selecting the large-delayed reward in delay-discounting might actually increase the experienced utility through "savouring" (Loewenstein, 1987, p.678). Individuals have also been shown to prefer a sequence where the outcome improves as opposed to deteriorates, even when outcomes were identical (Loewenstein & Prelac, 1991). Cognitive framing effects how individuals make current decisions (Tversky & Kahneman, 1981); therefore, future research should examine whether future losses or gains are discounted more readily as, anticipation of a negative outcome might be more influential to behaviour than expectation of a positive result.

The ability to control one's behaviour cannot only arise from simple avoidance temptation; in the vast majority of instances the rewards in question are too readily available so self-control must be, at least in part, internally generated (Ainslie, 2012). The suggested spring from which this ability flows has been explained in a number of ways; some have suggested that self-control as a 'moral muscle' that must be strengthened and trained (Muraven & Baumeister, 2000). For this reason, it has been suggested, that an intervention which focuses on reducing impulsive decision-making by training individuals to delay gratification could potentially have the effect of reducing negative health behaviours, including addiction (Koffarnus, Jarmolowicz, Mueller & Bickel, 2013). Alternatively, others have suggested that self-control is derived from viewing one's choices in a sequence and attempting to focus on the '*global*', rather than the immediately available, *'local'* reward (Rachlin, 1995; Kirby & Guastello, 2001). One means of achieving this is to engage in

reward bundling wherein multiple future decisions are made at a single time point (Ainslie & Monterosso, 2003); which decreases the preference for the smaller sooner reward *in lieu* of the larger later option (Hofmeyr, Ainslie, Charlton, & Ross, 2011). Based on this principal, Thaler and Benartzi (2004) developed the Save More Tomorrow (SMT) plan, which aids families in saving for their future; this opt-in strategy works on the basis of reward bundling, where the amount one saves gradually increases until a pre-set maximum and has shown to be very effective. However, while the benefits of reward bundling are apparent in this instance, it seems unclear how reward bundling could be a viable option for most decision making circumstances (Read, Loewenstein & Rabin, 1999).

8.7.: The difference between probability- and delay-discounting

A number of parallels between delay- and probability-discounting have been drawn. Firstly, both are modelled most accurately using the hyperbolic function (Rachlin, Raineri, & Cross, 1991). Second, both can be described, as they have throughout this thesis, in terms of cost; increasing delay or decreasing probability lowers the utility of the reward so can be conceived as a cost. With this in mind, delayed rewards could be described as probabilistic in that as time progresses reward receipt becomes less likely (Green & Myerson, 1986). Conversely, probabilistic rewards could be described in terms of delay, as repeated attempts to acquire an unlikely reward would take time, meaning ultimate reward receipt would be delayed (Rachlin, Logue, Gibbon, & Frankel, 1986). In support of this notion, there are a number of studies which show a positive relationship between probability- and delay-discounting rates (Myerson, Green, Hanson, Holt, & Estle, 2003; Richards, Zhang, Mitchell, & de Wit, 1999; Ohmura, Takahashi & Kitamura, 2005; Reynolds, Richards, Horn, & Karraker, 2004), leading some to suggest that the effect of lowered probability and increased delay on subsequent decisions is functionally equivalent (Rachlin, Raineri, & Cross, 1991; Keren & Roelofsma, 1995).

Conversely, others have argued that the effect of delay and risk on choice are independent (Christensen, Parker, Silberberg, & Hursh, 1998) as the relationship between probability- and delay-discounting measures is not universal, with some studies showing the correlation to be negative (Shead & Hodgins, 2009). Furthermore, on an intuitive level; those individuals who are more likely to gamble when the chance of winning is slim can be dubbed "risk-seeking"; conversely, those who avoid such gambles can be termed "risk averse". Those individuals who were risk averse would be more likely to select the smaller more certain reward faster than the risk seeking which means their indifference point would be reached more rapidly. If delay- and

probability-discounting are part of the same unitary construct then we would expect those individuals who selected the small-certain reward to also select the smaller-sooner reward, making them both delay and risk- averse, which is contrary to our understanding of impulsivity (Richards et al., 1999).

While steeper delay-discounting rate is robustly correlated to substance abuse, the same cannot be said for probability-discounting (Yi, Mitchell & Bickel, 2010). There is limited evidence that probabilistic discounting can differentiate between smokers and non-smokers (Reynolds, Richards, Horn, & Karraker, 2004; chapter 7) though, other studies have failed to find any significant difference (Mitchell, 1999; Ohmura et al., 2005). A potential explanation for why delay-, but not probability-, discounting can differentiate between smokers and non-smokers or drug abusers and non-drug abusers is that the delay-discounting process is more closely related to trait impulsivity or self-control (Andrade & Petry, 2012) than probability-discounting, which has been described as a metric of risk-seeking or aversion (Weatherly, Petros, Jónsdóttir, Derenne & Miller, 2015). While both traits of risk seeking and impulsivity are highly represented in substance abusing populations, they are associated with different abuse patterns; sensation seeking with stimulants and impulsivity with chronic drug exposure (Ersche, Turton, Pradhan, Bullmore, & Robbins, 2010). In an adolescent population, impulsivity scores were a stronger predictor of drug use and gambling than sensation seeking; which was a better predictor of smoking behaviour than impulsivity (Leeman, Krishnan-Sarin, & Potenza, 2014).

8.8.: Methodological limitations

8.8.1.: The unrestrained participant

In Pavlov's original experiments, in order to be able to collect the salvia accurately, the dogs were restrained. This meant that the range of movements the animals could engage in was severely restricted. According to an observational account by Liddell (unpublished, as cited in Timberlake & Grant, 1975), when the restraints were removed there was evidence for conditioned responding from the animals, specifically begging. In 1937, Zener conducted a series of experiments very similar to Pavlov's but did so with the animals "loosely secured" (p.389) and later unrestrained. With this new scope for movements, the dogs displayed a variety of behaviours including orienting towards the bell or food pan, approaching the bell, licking the bell or the food pan, chewing behaviour and a small proportion of dogs *moved away* from the food pan

in the time between CS presentation and US delivery (Zener, 1937). Removing the animals' bonds revealed a complex repertoire of behaviours hitherto unobserved. In recent years computers have become an indispensable tool in everyday life as well as in research, and a growing number of modes of assessment have come to be computer based (Oeberst, Haberstroh & Gnambs, 2015). Perhaps ironically then, this shift in data collection from modelling behaviour using a small-scale behavioural tasks to computer-based tasks, could restrict the scope of our analyses of human behaviour in the same way as was the case in Pavlov's lab. Where non-human subjects are free to respond and move around the conditioning chamber, our human participants are bound to the computers. While there is evidence to suggest that computer-based questionnaire responses do not differ from pen-and-paper results (Petite, 2002; Gosling et al., 2004; Smith & Hantula, 2008), a recent study by Oeberst et al. (2015) demonstrated that a computer-based lottery task over-estimated participants' risk seeking behaviour compared to the same lottery task performed in-person in the lab.

However, there are two major developments in psychological research that could mitigate or even eliminate this concern. The first is, as used in chapter 4 and previously described (Le Pelley et al., 2015; Versace et al., 2015; Garofalo & di Pellegrino, 2015), the use of eye-tracking in behavioural tasks. Over the last couple of decades, there have been critical advances in the quality of eye-tracking data technology and how it is collected and analysed (Jacob & Karn, 2003; Mele & Federici, 2012). Furthermore, eye-tracking data can be used for a multitude of assessments including attention (Wills, Lavric, Croft, & Hodgson, 2007), problem-solving and search strategies (Jacob & Karn, 2003). As such, eye-tracking provides a means of assessing in more detail the responses given by our human participants. A recent example of this was conducted comparing adolescent and young adult participants in a decision making task; participants were presented with gamble alternatives, not dissimilar to the discounting items presented in chapter 6, and response rates and eye-movements were compared. Discounting rates have been repeatedly demonstrated to be most rapid during childhood and decrease across lifespan (Olsen, Hopper, Collins & Luciana, 2007; Green, Fry and Myerson, 1994; Green, Myerson, Lichtman, Rosen & Fry, 1996; Green, Myerson & Ostaszewski, 1999b) and this has led to the assertion that adolescent responders are more impulsive than adults. Results from the choice data revealed that adolescents selected the small-reward over the large-reward significantly more than adults; however, eye-tracking data showed that adolescents were actually more risk-averse, spent longer making each decision and were less reliant on heuristics than adults (Kwak, Payne, Cohen, & Huettel, 2015).The results from this experiment demonstrate the value of utilising eye-tracking

experiments and the novel insight it can provide into *how* such responses are made rather than just *what* those responses were (Franco-Watkins & Johnson, 2011).

The second major development in the field of behavioural psychology is the use of mobile devices and smartphone in data collection (Miller, 2012), which allows for the extended collection of objective data (Gosling & Mason, 2015). Without delving into this issue extensively, smartphones provide a means of collecting extensive, real time data in an accurate way from a wide spectrum of participants (Harari, Gosling, Wang & Campbell, 2015). Smart phones allow for the exploration of human behavioural repertoires and, as such, could transform methods of data collection immeasurably (Miller, 2012). Pertaining to this thesis, if irrational decisions stem from an under-utilized self-regulatory process (Baumeister & Heatherton, 1996; Hofmann, Friese, & Roefs, 2009), smart phones could provide significant therapeutic value as they can be used to administer interventions as and when they are needed (Lathia et al., 2013).

8.9.: Future directions

8.9.1.: Hedonistically irrational decisions

The brain is extremely sensitive to cues, rapidly responding to positive cues (Garavan, Pendergrass, Ross, Stein, & Risinger, 2001) even when presented for less than half a second and are, positive, but irrelevant to survival (Childress et al., 2008). Even if cues are not recognised, they can influence cognition or behaviour via rationalisations (Robinson & Berridge, 1993). The rapid reacquisition of responding observed in sign-, and more recently goal-trackers, bears a remarkable resemblance to behaviours observed in drug addicts (Tomie, 1995; 1996), better understanding of which could help elucidate a number of facets of the drug addiction process (Corbit & Janak, 2007).

Future directions based on the results described here would be to further examine the effect of devaluation on sign- and goal-tracking, as discussed in chapter 3. In order to assess this, use of multiple reinforcers, as previously done by Johnson, Gallagher and Holland (2009), would help elucidate the effect of altering reward value on sign- and goal-directed behaviours more accurately. Furthermore, having established a model of sign- and goal-tracking in humans this effect can also be simultaneously examined in humans. As animal research has demonstrated differences in propensity to self-administer drugs in sign- and goal-tracking rats (Beckmann et al., 2011) another future investigation in sign- and goal-tracking in humans would be to study the

difference in proclivity to attend to the goal or the cue across drug- naïve and substance-abusing participants.

While Garofalo & di Pellegrino (2015) successfully designated their participants using the PCA index (Meyer et al., 2012), in chapter 4, the PCG classifications were developed as an alternative designation. A potential explanation for why the PCA index was inappropriate in the current methodology relates to the use of three reward contingencies; therefore, a future experiment would be to replicate the paradigm using two reward probabilities and to compare the designations attributed via both classifications.

8.9.2.: Economically irrational decisions

Based on the results of this series, delay- and probability-discounting represent distinct but related constructs. In support of research suggesting that probability and delay-discounting are distinct but related processes, Chapter 5 demonstrated that probability-, but not delay-, discounting was sensitive to pre-exposure to reward. Chapter 6 showed that reward devaluation had a differential effect across BIS-11 classifications for both probability- and delay-discounting assessments. Furthermore, the motor and non-planning subscales of the BIS-11 were found to significantly correlate with and predict delay-discounting rates (Chapter 7). This is in accordance with previous research demonstrating that the non-planning subscale of the BIS-11 to positively correlates with (de Wit et al., 2007) and predicts (Koff & Lucas, 2011) delay-discounting rate. Previous research has demonstrated no significant correlation between the BIS-11 and probability-discounting rates (Mitchell, 1999; Reynolds, Penfold & Patak, 2008), corresponding with the results of chapter 7. However, discounting rates for both delayed and probabilistic rewards modestly correlated with the impulsivity and extroversion subscale of the Eysenck Personality Index and disinhibition subscale of the Sensation Seeking Scale) (Richards, Zhang, Mitchell, & de Wit 1999). However, in order to elucidate the relationship between sensation-seeking, impulsivity, delay- and probability-discounting useful future experiments would use a variety if impulsivity assessments in conjunction with the *BIS-11* to investigate the associations in more detail.

8.9.3.: Hedonistically and Economically irrational decisions

However, impulsivity is a multi-faceted construct (Caswell, 2013; Diergaarde et al., 2008; Broos et al., 2012); two recognised facets of which are *impulsive-choice* and *impulsive-action*. Impulsive choice refers to impulsive decision making, wherein an impulsive choice is the selection of the smaller-sooner reward over the larger-later reward (Broos et al., 2012; see chapters 5 and 6). Conversely, impulsive-action refers to the inability to withhold inappropriate actions (inhibitory control) (Diergaarde et al., 2008). A recent animal study compared impulsivity across conditioned response groups and found sign-trackers were less impulsive in measures of impulsive choice (delay-discounting) but more impulsive in a measure of impulsive-action (5-CSRTT) than goal-trackers (Lovic et al., 2011). Therefore, a future direction of research would be to examine impulsivity using a battery of tests, including self-report and behavioural, in order to assess the relationship between impulsive action and choice and sign- and goal-tracking; with the intention of establishing a metric for susceptibility to particular cue types (contextual or discrete) and the long term aim of tailoring therapeutic interventions to the individual needs of each individual.

8.9.4.: Potential applications for treatment

This thesis sets out methodological procedures for the assessment of irrational decision making in the lab, however, it does so with the aspiration of being potentially insightful into the nature of maladaptive behaviours such as drug addiction. With this in mind, what follows is a brief description of potential applications of the findings herein to reducing irrational decision-making.

It has been argued that as delay-discounting could be used as a metric of one's subjective craving (Asche, Newman & Wilson, 2015) and as such could be of therapeutic use in selection of intervention methods. However, as 'rational' decisions in both discounting and sign- and goal-tracking involve self-control (i.e. resisting the urge to select the smaller sooner reward and to ignore incentive cues), there are few intervention methods that might aid in the reduction of irrational responding in both. The first is self-imposed *commitment contracts*, wherein an individual sets conditions in order to avoid preference reversals. Although, such contracts are more effective when they are motivated by reward ('carrots') than punishment ('sticks' or 'binding') Peysakhovich (2014). Examples of such might be, "if I stop drinking for the month of January, I will spend all the money I save on a treat for myself". Alternatively, *mindfulness*, the practice of moment-to-moment awareness (Ashe et al. 2015), has been shown to significantly affect discounting of food rewards, although discounting for money was unaffected (Hendrickson &

Rasmussen, 2013). Finally, *distraction* strategies, such as removing oneself from the tempting situation and engaging in an alternative activity, significantly reduces craving for alcohol (Murphy & MacKillop, 2014) and, therefore, would be therapeutically useful in training against irrational decisions.

8.9.5.: Conclusions

In this translational thesis, I presented novel, homologous tasks which demonstrated that hedonistically and economically irrational decisions occur as a result of changes in reward utility as a function of delay (chapters 5, 6 and 7), probability (chapters 1-7), devaluation (chapter 3 and 5) and individual differences (chapters 3, 4, 6 and 7).

For economically irrational decisions, when subjective costs of delay or probability were applied, utility was shown to decrease, as predicted, in novel mouse (chapter 5) and human (chapter 6) models. In accordance with existing literature (Kirby, 1997; Weber &Chapman, 2005), the peanut (chapter 3, 6 and 7) and magnitude effects (Chapter 3 and 7) were observed. For probability discounting, devaluation of the reward eliminated the peanut effect (for further discussion see chapter 6) but delay discounting was unaffected, supporting the assertion that reward utility influences probability- and delay-discounting differently (Green & Myerson, 2004; Green, Myerson, & Ostaszewski, 1999; Myerson, Green, Hanson, Holt, & Estle, 2003). Taken in conjunction with the finding that BIS-11 score correlated with delay- but not probability-discounting, this thesis contributes to the increasing body of evidence that the discounting of probabilistic and delayed rewards are mediated by dissociable mechanisms and, therefore, are related but distinct processes of utility devaluation (see st Onge & Floresco, 2009 for a review, and section 8.7).

For hedonistically irrational decisions, in accordance with previous research (Anselme et al., 2012; Boakes, 1977) reducing probability of reward receipt potentiated sign-directed responses overall, but when split into sign-and goal-trackers, reductions in reward probability increased sign- and goal directed responses respectively (chapter 3). In chapter 3, devaluation of reward utility was shown to increase sign-tracking responses relative to goal-directed responses. This supports the argument that sign-tracking is produced by an increase in decision utility compared to predicted/remembered or experienced utility (Berridge & O'Doherty, 2014).

There is evidence in existing literature (Saunders & Robinson, 2010; Flagel, Akil & Robinson, 2009; Flagel et al. 2007) that the attribution of incentive salience (decision utility) is partially determined by individual differences; however, the results from chapter 4 did not identify any differences across Pavlovian conditioned gaze (PCG) classifications. However, results indicated that propensity to exhibit sign- or goal-directed responses can be influenced by procedural factors such as exposure to manipulandum in animals (chapter 3) or context (experiments 4.1 and 4.3, chapter 4).

The evidence presented in this thesis will inform further studies to clarify the effect of presentation order in probability- and delay-discounting paradigms and the influence of individual differences in sign- and goal-tracking in humans.

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10. Appendices.

Appendix 1: General Methods

Appendix 1.1: Barratt Impulsivity Scale version 11 (BIS-11)

DIRECTIONS: People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Read each statement and put an X in the appropriate column on the right side of this page. Do not spend too much time on any statement. Answer quickly and honestly.

	Rarely/Never	Occasionally	Often	Almost Always/ Always
1 I plan tasks carefully.				
2 I do things without thinking.				
3 I make-up my mind quickly.				
4 I am happy-go-lucky.				
5 I don't "pay attention."				
6 I have "racing" thoughts.				
7 I plan trips well ahead of time.				
8 I am self-controlled.				
9 I concentrate easily.				
10 I save regularly.				
11 I "squirm" at plays or lectures.				
12 I am a careful thinker.				
13 I plan for job security.				
14 I say things without thinking.				
15 I like to think about complex problems.				
16 I change jobs.				
17 I act "on impulse."				
18 I get easily bored when solving thought problems.				
19 I act on the spur of the moment.				
20 I am a steady thinker.				
21 I change residences.				
22 I buy things on impulse.				
23 I can only think about one thing at a time.				
24 I change hobbies.				
25 I spend or charge more than I earn.				
26 I often have extraneous thoughts when thinking.				
27 I am more interested in the present than the future.				
28 I am restless at the theater or lectures.				
29 I like puzzles.				
30 I am future oriented.				

Appendix 1.2: Kirby, Petry and Bickel (1999) delay discounting questionnaire:

Would you prefer…

	immediate cash	delayed cash
£54 today, or £55 in 117 days?	❍	❍
£55 today, or £75 in 61 days?	❍	❍
£19 today, or £25 in 53 days?	❍	❍
£31 today, or £85 in 7 days?	❍	❍
£14 today, or £25 in 19 days?	❍	❍
£47 today, or £50 in 160 days?	❍	❍
£15 today, or £35 in 13 days?	❍	❍
£25 today, or £60 in 14 days?	❍	❍
£78 today, or £80 in 162 days?	❍	❍
£40 today, or £55 in 62 days?	❍	❍
£11 today, or £30 in 7 days?	❍	❍
£67 today, or £75 in 119 days?	❍	❍
£34 today, or £35 in 186 days?	❍	❍
£27 today, or £50 in 21 days?	❍	❍
£69 today, or £85 in 91 days?	❍	❍
£49 today, or £60 in 89 days?	❍	❍
£80 today, or £85 in 157 days?	❍	❍
£24 today, or £35 in 29 days?	❍	❍
£33 today, or £80 in 14 days?	❍	❍
£28 today, or £30 in 179 days?	❍	❍
£34 today, or £50 in 30 days?	❍	❍
£25 today, or £30 in 80 days?	❍	❍
£41 today, or £75 in 20 days?	❍	❍
£54 today, or £60 in 111 days?	❍	❍
£54 today, or £80 in 30 days?	❍	❍
£22 today, or £25 in 136 days?	❍	❍
£20 today, or £55 in 7 days?	❍	❍

Appendix 1.3: Madden, Petry & Johnson's (2009) probability discounting questionnaire:

Would you prefer:

	Certain Cash	Probabilistic Cash
Would you prefer $20 for sure or a 1-in-10 chance (10%) of winning $80?		
Would you prefer $20 for sure or a 1-in-8 chance (13%) of winning $80?		
Would you prefer $20 for sure or a 1-in-6 chance (17%) of winning $80?		
Would you prefer $20 for sure or a 1-in-5 chance (20%) of winning $80?		
Would you prefer $20 for sure or a 1-in-4 chance (25%) of winning $80?		
Would you prefer $20 for sure or a 1-in-3 chance (33%) of winning $80?		
Would you prefer $20 for sure or a 1-in-2 chance (50%) of winning $80?		
Would you prefer $20 for sure or a 2-in-3 chance (67%) of winning $80?		
Would you prefer $20 for sure or a 3-in-4 chance (75%) of winning $80?		
Would you prefer $20 for sure or a 5-in-6 chance (83%) of winning $80?		
Would you prefer $40 for sure or a 2-in-11 chance (18%) of winning $100?		
Would you prefer $40 for sure or a 2-in-9 chance (22%) of winning $100?		
Would you prefer $40 for sure or a 2-in-7 chance (29%) of winning $100?		
Would you prefer $40 for sure or a 1-in-3 chance (33%) of winning $100?		
Would you prefer $40 for sure or a 2-in-5 chance (40%) of winning $100?		
Would you prefer $40 for sure or a 1-in-2 chance (50%) of winning $100?		
Would you prefer $40 for sure or a 2-in-3 chance (67%) of winning $100?		
Would you prefer $40 for sure or a 4-in-5 chance (80%) of winning $100?		
Would you prefer $40 for sure or a 6-in-7 chance (86%) of winning $100?		
Would you prefer $40 for sure or a 10-in-11 chance (91%) of winning $100?		
Would you prefer $40 for sure or a 2-in-5 chance (40%) of winning $60?		
Would you prefer $40 for sure or a 6-in-13 chance (46%) of winning $60?		
Would you prefer $40 for sure or a 6-in-11 chance (55%) of winning $60?		
Would you prefer $40 for sure or a 3-in-5 chance (60%) of winning $60?		
Would you prefer $40 for sure or a 2-in-3 chance (67%) of winning $60?		
Would you prefer $40 for sure or a 3-in-4 chance (75%) of winning $60?		
Would you prefer $40 for sure or a 6-in-7 chance (86%) of winning $60?		
Would you prefer $40 for sure or a 12-in-13 chance (92%) of winning $60?		
Would you prefer $40 for sure or a 18-in-19 chance (95%) of winning $60?		
Would you prefer $40 for sure or a 30-in-31 chance (97%) of winning $60?		

Appendix 1.4: Alcohol Use Questionnaire:

Alcohol use questionnaire

Q1 On how many days per week do you drink wine, or any wine-type product, e.g. sherry, port, martini?

Q2 Please state your usual brand(s)

Q3 On those days you do drink wine (or similar), about how many glasses (pub measure) do you drink?

Q4 If unsure, please estimate the number of bottles or parts of a bottle

Q5 How many glasses (pub measure) of wine do you have in a week, in total?

Q6 On how many days per week do you drink beer or cider (at least half a pint)?

Q7 Please state usual brand(s) e.g. Carling, Harvey's, Strongbow:

Q8 On those days you do drink beer/cider, about how many pints do you typically have?

Q9 How many pints of beer/cider do you drink in a week, in total?

Q10 On how many days per week do you drink spirits (e.g. whisky, vodka, gin, rum)?

Q11 Please state usual brand(s) e.g. Smirnoff, Bells, Gordon's

Q12 On those days you do drink spirits, about how many shots (pub measure) do you typically have?

Q13 If unsure, please estimate number of bottles or parts of a bottle

Q14 How many drinks of spirits do you have in a week, in total?

Q15 On how many days per week do you drink alcopops?

Q16 Please state usual brand(s) e.g. Hooch, Bacardi Breezer, WKD:

Q17 On those days you drink alcopops, about how many bottles do you typically have?

Q18 How many bottles of alcopops do you have each week, in total?

Q19 When you drink, how fast do you drink? (Here, a drink is a glass of wine, a pint of beer, a shot of spirits, straight or mixed). Please check the correct response:

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7+ (7)
drinks per hour (1)	❍	❍	❍	❍	❍	❍	❍

Q20 How many times have you been drunk in the last 6 months? By 'drunk' we mean loss of co-ordination, nausea, and/or inability to speak clearly

Q21 What percentage of times that you drink do you get drunk?

Q22 At what age did you start drinking?

Q23 Do you have anyone in your close family who was alcoholic? Please circle correct response:

❍ Yes
❍ No

Q24 If yes, what relation are they to you?

Appendix 1.5: Drug Use Questionnaire (DUQ)

Drug Use Questionnaire

Q1 If you have used any of the following please check the box. If you have not used any of the items please check the final option and submit the questionnaire.

If you select one or more of the items marked with an asterisk please state the type (for example: Amobarbital, Barbital, Phenobarbital, diazepam, valium, citalopram,paroxetine , sertraline, duloxetine , venlafaxine, Mirtazapine)

- ❑ Marijuana
- ❑ Cannabis
- ❑ Hashish
- ❑ Cocaine
- ❑ Crack
- ❑ Mephedrone (M-CAT)
- ❑ Speed
- ❑ MDMA/Ecstasy
- ❑ Magic Mushrooms
- ❑ LSD
- ❑ 2-CB
- ❑ 2-CI
- ❑ 2-CP
- ❑ PCP
- ❑ Mescaline
- ❑ Ketamine
- ❑ Nitrous Oxide (nos)
- ❑ Heroin
- ❑ Morphine
- ❑ Downers* _____
- ❑ Tranquilizers* _____
- ❑ Anti-depressants* _____
- ❑ Poppers
- ❑ Glue
- ❑ I have never used any of these items before

Q3 For each of the items you have used could you please answer the following

	what is the duration of item use? (mths-yrs)? (date of initiation)		How long has it been since you have used this item? (days-yrs)	
	months	years	days	years
Marijuana				
Cannabis				
Hashish				
Cocaine				
Crack				
Mephedrone				
Speed				
MDMA/Ectasy				
Magic Mushrooms				
LSD				
2-CB				
2-CI				
2-CP				
PCP				
Mescaline				
Ketamine				
Nitrous Oxide (nos)				
Heroin				
Morphine				
Glue				
Poppers				
Downers				
Tranquilizers				
anti-depressants				

Q4 Approximately, how often do you use this item per day, week, month and year?

	how often have you used this item? (per wk/mths/yrs)			
	…per day	…per week	…per month	…per year
Marijuana				
Cannabis				
Hashish				
Cocaine				
Crack				
Mephedrone				
Speed				
MDMA/Ectasy				
Magic Mushrooms				
LSD				
2-CB				
2-CI				
2-CP				
PCP				
Mescaline				
Ketamine				
Nitrous Oxide (nos)				
Heroin				
Morphine				
Glue				
Poppers				
Downers				
Tranquilizers				
anti-depressants				

Q6 please state your usual dose per session

	usual dose per session
» Marijuana (joints)	
» Marijuana (bong or vapourizer hit)	
» Cannabis (joints)	
Cannabis (bong or vapourizer hit)	
» Hashish (joints)	
» Cocaine (grams)	
» Crack (grams)	
» Mephedrone (M-CAT) (grams)	
» Speed (grams)	
» MDMA/Ectasy (grams/pills)	
» Magic Mushrooms (hits)	
» LSD (hits)	
» 2-CB (hits)	
» 2-CI (hits)	
» 2-CP (hits)	
» PCP (hits)	
» Mescaline (hits)	
» Ketamine (hits)	
Nitrous Oxide (nos) (cannisters/balloons)	
» Heroin (grams)	
» Morphine(grams)	
» Glue (hits)	
» Poppers(hits)	
» Downers(tablets/dosage)	
» Tranquilizers(tablets/dosage)	
» anti-depressants (tablets/dosage)	

Appendix 1.6: Medical History Questionnaire

Medical History Questionnaire

Confidential

Please complete all sections of this form unless otherwise indicated.

Age…… Sex…… Height…… Weight……

Please highlight the appropriate answer where a **'Yes'** or **'No'** is required. If your answer is **'Yes'** brief details should be given.

1. Have you suffered from any of the following?

		Details
Diabetes Mellitus	**Yes / No**	
Epilepsy	**Yes /** No	
Frequent chest, throat or nose infections/diseases	**Yes / No**	
Back injury/backache	**Yes / No**	
Joint injury	**Yes / No**	
Ear infection	**Yes / No**	
Rheumatism or Rheumatic fever	**Yes / No**	
Urinary problems or kidney disease	**Yes / No**	
Infectious diseases (Mumps, Measles, German Measles, Tuberculosis etc.)	**Yes / No**	
Hepatitis	**Yes / No**	
Heart disease	**Yes / No**	
High blood pressure, chest pain, shortage of breath	**Yes / No**	
Anxiety or Depression requiring treatment	**Yes / No**	
Nervous breakdown or debility arising from overwork	**Yes / No**	
Menstrual problems	**Yes / No**	
Haemorrhoids	**Yes / No**	
Dyspepsia or Peptic Ulcer	**Yes / No**	
Hernia	**Yes / No**	
Dysentry/Typhoid/Food poisoning	**Yes / No**	
Any other stomach disorder	**Yes / No**	
Varicose veins	**Yes / No**	
Migraines or other frequent headaches	**Yes / No**	
Hay fever, eczema or other allergies	**Yes / No**	
Skin disorders	**Yes / No**	
Fainting or giddiness	**Yes / No**	
Poor eyesight (even when wearing glasses/contact lenses)	**Yes / No**	
Please give date when eyesight was last tested (approx.)	**Yes / No**	
Impaired hearing	**Yes / No**	

2.	Are you a registered disabled person?	**Yes / No**	If **'Yes'** what is you registration number and expiry date?
3.	a) Have you been an in-patient in hospital or consulted your GP during the last five years?	**Yes / No**	If **'Yes'** please give details:
	b) How many days of sickness have you had in the last 12 months?		What were the main causes?
	c) Are you taking any pills, tablets or having injections, receiving any medical or psychiatric treatment or advice or awaiting surgery?	**Yes / No**	If **'Yes'** please give details:
4.	How often do you visit your dentist?		When was your last visit?
5.	What was the date of your last immunisation against the following: (approx.)		Tetanus- Tuberculosis Polio Rubella (German Measles) (Anti-D Gammaglobulin)? Hepatitis B-
6.	Date of last x-ray		Reason for x-ray
7.	General state of health; please comment on any aspects not covered above (i.e. accidents, injuries, disorders not mentioned).		
8.	What is your average consumption of measure /one glass of wine/ of beer)	a) alcohol	units* per week 0-5(* A unit- single measure of spirit half a pint
		b) tobacco	per day

9. Is there any additional information regarding your health not covered in the above questions?

I declare that the answers given to the above questions are true to the best of my knowledge and I have not withheld any material facts which may have any bearing as to the state of my health.

Signature Date

Appendix 2: sign and goal-tracking in humans

Participant number	PCA index	Participant number	PCA index
1123	-0.06	6358	0.01
1211	0.04	6401	0.00
1404	0.00	6474	0.06
1655	0.07	6475	-0.05
1850	-0.14	6621	-0.01
1975	0.00	6671	-0.09
2612	-0.01	6849	-0.15
2683	0.19	7145	-0.02
3095	0.00	7256	-0.06
3344	-0.13	7274	-0.03
3345	-0.02	7384	-0.01
3552	0.08	7715	-0.11
3735	-0.12	7728	0.00
3763	-0.74**	8010	0.01
3866	0.00	8210	0.07
3894	0.03	8217	-0.16
3956	-0.03	8479	0.01
4015	-0.31	8503	-0.32
4308	-0.03	8571	0.02
4384	-0.06	8670	0.04
4508	0.16	8883	0.04
4984	-0.04	8954	-0.05
5224	0.00	8986	-0.17
5291	0.00	9139	-0.12
5428	0.00	9208	0.08
5629	-0.01	9281	-0.02
5642	-0.09	9342	-0.19
5691	0.08	9646	0.05
5745	-0.09	9719	0.03
6035	0.10	9893	0.00
6072	0.00	9927	-0.05
6117	0.06	9928	0.05
6324	0.01	9969	-0.27

Appendix Table 2.1: shows PCA index for each participant in experiment 4.1, calculated using *dwell time* from the last 3 *blocks* of training. **denotes participant whose PCA index score allows for classification.

Grouping variables	Goal-Tracker	Intermediate	Sign-Tracker	total
PCG class	8	39	17	64
Sex:				
Male:	4	20	8	32
female	4	19	9	32
Smoker:				
Smoker:	1	7	5	13
Non-smoker:	7	32	12	51
Awareness:				
Aware:	4	25	11	40
Unaware:	4	14	6	24
Binge class.				
Binger:	2	13	6	21
Non-Binger:	3	14	4	21*
Poly drug class.				
Poly-drug	4	18	7	29
Mono-drug/ Drug naïve	4	21	10	35

Appendix Table 2.2: shows n of each of the grouping variables across Pavlovian Conditioned Gaze classifications. * Participants with an "unclassifiable" binge score were not included in the analysis (experiment 4.1)

Behavioural measure	Main effect of *Contingency*
Fixation count	$F(2,126) = 0.94$, $p = .399$
Dwell time	$F(2,126) = 0.63$, $p = .533$
Latency	$F(1.81, 114.01) = 0.62$, $p = .525$
Run Count	$F(2,126) = 1.23$, $p = .295$
% pupil change	$F(1.50, 91.17) = 2.18$, $p = .132$

Appendix Table 2.3: shows the effect of *contingency* alone across eye-tracking measures (Experiment 4.1)

Behavioural measure	Main effect of *image*
Fixation count	$t(63) = -2.28$, $p = .007$
Dwell time	$t(63) = -2.68$, $p = .009$
Latency	$t(63) = -2.34$, $p = .022$
Run Count	$t(63) = -2.52$, $p = .014$
% pupil change	$t(63) = -1.56$, $p = .125$

Appendix Table 2.4: shows the effect of *image* alone across eye-tracking measures (Experiment 4.1)

Behavioural measure	**Interaction between *Awareness* and *PCG classification***
Fixation count	$F(2,58) = 1.77$, $p = .179$
Dwell time	$F(2,58) = 0.84$, $p = .437$
Latency	$F(2,58) = 1.89$, $p = .159$
Run Count	$F(2,58) = 1.08$, $p = .348$
% pupil change	$F(2,58) = 0.63$, $p = .534$

Appendix Table 2.4: shows the effect of awareness across *PCG classification* on total fixation count, dwell time, latency and run count (Experiment 4.1)

Behavioural measure	**Interaction between *Awareness, PCG classification* and *contingency***
Fixation count	$F(4,116) = 0.55$, $p = .700$
Dwell time	$F(4,116) = 0.97$, $p = .429$
Run Count	$F(4,116) = 0.28$, $p = .892$
Latency	$F(3.53, 102.23) = 0.31$, $p = .873$
% pupil change	$F(3.01, 84.16) = 0.32$, $p = .810$

Appendix Table 2.5: shows the effect of awareness across *contingencies* between *PCG classification* on total fixation count, dwell time, latency and run count (Experiment 4.1; *M*s and *SE*s in table 5A)

Behavioural measure	**Interaction between *Awareness, PCG classification, contingency* and *image***
Fixation count	$F(3.67, 106.31) = 0.21$, $p = .920$
Dwell time	$F(3.84,111.22) = 0.03$, $p = .997$
Run Count	$F(3.42, 99.25) = 0.22$, $p = .903$
Latency	$F(3.84,111.22) = 0.03$, $p = .997$
% pupil change	$F(3.85, 108) = 2.01$, $p = .098$

Appendix Table 2.6: shows the effect of awareness across *contingencies* between *PCG classification* on total fixation count, dwell time, latency and run count (Experiment 4.1; *M*s and *SE*s in table 5B)

	Aware						Unaware					
	CS10		CS50		CS90		CS10		CS50		CS90	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Fixation count												
Goal-Tracker	1.01	0.19	1.01	0.19	0.92	0.19	1.13	0.19	1.09	0.19	1.05	0.19
Intermediate	0.97	0.08	0.98	0.08	0.98	0.08	0.62	0.10	0.60	0.10	0.61	0.10
Sign-Tracker	1.17	0.12	1.16	0.11	1.15	0.11	1.09	0.16	1.12	0.15	1.05	0.15
Dwell Time												
Goal-Tracker	212.29	36.95	219.38	36.32	206.80	36.50	218.01	36.95	228.43	36.32	211.25	36.50
Intermediate	176.89	14.78	180.86	14.53	183.47	14.60	129.46	19.75	122.05	19.41	127.58	19.51
Sign-Tracker	246.54	22.28	248.80	21.90	237.30	22.01	225.48	30.17	241.68	29.65	229.01	29.80
Latency												
Goal-Tracker	2083.52	135.26	2092.06	140.29	2136.10	140.58	2299.93	135.26	2257.71	140.29	2298.40	140.58
Intermediate	2080.02	54.10	2091.08	56.12	2073.74	56.23	2405.42	72.30	2408.30	74.99	2413.48	75.15
Sign-Tracker	2039.67	81.57	2060.63	84.60	2079.95	84.78	2151.08	110.44	2175.74	114.55	2181.92	114.79
Run Count												
Goal-Tracker	0.70	0.12	0.70	0.12	0.65	0.12	0.55	0.12	0.57	0.12	0.53	0.12
Intermediate	0.71	0.05	0.70	0.05	0.70	0.05	0.42	0.07	0.42	0.07	0.42	0.07
Sign-Tracker	0.73	0.07	0.72	0.08	0.71	0.08	0.67	0.10	0.65	0.10	0.63	0.10
Pupil change												
Goal-Tracker	-0.55	1.24	0.59	1.17	-0.29	1.29	-1.51	1.24	0.67	1.17	0.70	1.29
Intermediate	-0.09	0.51	0.12	0.48	0.04	0.53	-1.45	0.69	1.49	0.65	0.51	0.72
Sign-Tracker	-0.11	0.75	0.43	0.71	-0.35	0.78	-0.39	1.02	0.27	0.96	-0.33	1.05

Appendix Table 2.7: shows the fixation count, dwell time, run count, latency and pupil change split by *awareness, contingency* and *PCG classifications. Aware goal-trackers N=4, unaware goal-trackers N=4, aware intermediates N=25, unaware intermediates N=14, aware sign-trackers N=11, unaware sign-trackers N=6.*

	Cue						Goal					
	CS10		CS50		CS90		goal10		goal50		goal90	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Fixation count												
Aware												
Goal-Tracker	0.63	0.22	0.59	0.23	0.59	0.23	1.40	0.22	1.43	0.21	1.25	0.23
Intermediate	1.00	0.09	1.07	0.09	1.14	0.09	0.94	0.09	0.88	0.08	0.82	0.09
Sign-Tracker	1.74	0.13	1.76	0.14	1.76	0.14	0.59	0.13	0.57	0.13	0.54	0.14
Unaware												
Goal-Tracker	0.65	0.22	0.73	0.23	0.68	0.23	1.60	0.22	1.45	0.21	1.42	0.23
Intermediate	0.52	0.12	0.59	0.12	0.56	0.13	0.72	0.12	0.61	0.11	0.66	0.12
Sign-Tracker	1.60	0.18	1.66	0.19	1.55	0.19	0.58	0.18	0.58	0.17	0.55	0.19
Dwell Time												
Aware												
Goal-Tracker	97.50	42.17	104.84	48.48	104.58	49.41	327.08	44.57	333.92	39.98	309.02	45.13
Intermediate	186.91	16.87	204.55	19.39	215.04	19.77	166.88	17.83	157.16	15.99	151.89	18.05
Sign-Tracker	380.36	25.43	393.62	29.24	378.43	29.80	112.72	26.87	103.97	24.11	96.17	27.22
Unaware												
Goal-Tracker	110.17	42.17	124.02	48.48	109.98	49.41	325.85	44.57	332.83	39.98	312.52	45.13
Intermediate	104.57	22.54	125.22	25.92	126.42	26.41	154.36	23.82	118.87	21.37	128.74	24.13
Sign-Tracker	327.43	34.43	371.22	39.59	347.17	40.35	123.53	36.39	112.15	32.64	110.84	36.85
Latency												
Aware												
Goal-Tracker	2341.01	147.32	2362.57	154.00	2370.35	155.46	1826.03	163.17	1821.55	164.85	1901.85	184.77
Intermediate	2057.50	58.93	2014.46	61.60	1917.92	62.18	2102.54	65.27	2167.71	65.94	2229.56	73.91
Sign-Tracker	1798.06	88.83	1810.17	92.87	1773.47	93.75	2281.28	98.39	2311.09	99.41	2386.43	111.42
Unaware												
Goal-Tracker	2558.54	147.32	2518.90	154.00	2535.21	155.46	2041.31	163.17	1996.53	164.85	2061.58	184.77
Intermediate	2466.41	78.74	2409.02	82.32	2452.89	83.10	2344.43	87.22	2407.58	88.12	2374.08	98.77
Sign-Tracker	1926.93	120.28	1937.75	125.74	1939.87	126.93	2375.24	133.23	2413.73	134.60	2423.98	150.87

Run Count												
Aware												
Goal-Tracker	0.44	0.13	0.43	0.13	0.41	0.12	0.97	0.15	0.98	0.15	0.89	0.16
Intermediate	0.71	0.05	0.76	0.05	0.81	0.05	0.70	0.06	0.64	0.06	0.59	0.07
Sign-Tracker	0.99	0.08	0.98	0.08	0.99	0.07	0.47	0.09	0.46	0.09	0.43	0.10
Unaware												
Goal-Tracker	0.32	0.13	0.34	0.13	0.34	0.12	0.78	0.15	0.79	0.15	0.73	0.16
Intermediate	0.37	0.07	0.41	0.07	0.39	0.07	0.48	0.08	0.43	0.08	0.45	0.09
Sign-Tracker	0.91	0.10	0.91	0.11	0.87	0.10	0.43	0.12	0.39	0.12	0.39	0.13
Pupil change												
Aware												
Goal-Tracker	0.69	2.34	3.40	2.33	1.31	2.35	-1.70	2.63	-1.33	3.17	-1.92	2.65
Intermediate	-0.10	0.96	0.02	0.95	-0.38	0.96	0.98	1.07	0.38	1.29	2.29	1.08
Sign-Tracker	-3.20	1.41	-2.22	1.41	-3.26	1.42	7.81	1.58	6.60	1.91	6.55	1.60
Unaware												
Goal-Tracker	-0.69	2.34	1.92	2.33	4.94	2.35	-1.54	2.63	0.70	3.17	0.00	2.65
Intermediate	1.54	1.41	0.10	1.41	1.08	1.42	-1.73	1.58	0.01	1.91	-1.69	1.60
Sign-Tracker	-1.47	1.91	-0.42	1.90	-1.33	1.92	1.29	2.14	-1.60	2.59	3.72	2.17

*Appendix Table 2.***8:** shows four way interaction contingency, awareness, PCG class. and image Aware goal-trackers *N*=4, unaware goal-trackers *N*=4, aware intermediates *N*=25, unaware intermediates *N*=14, aware sign-trackers *N*=11, unaware sign-trackers *N*=6.

	awareness by PCG classification	***stimuli by awareness by PCG classification***
pleasantness	F (2, 58)=0.26, p=.775	F (5.83, 169.09)=0.39, p=.887
anxiety	F (2, 58)=0.61, p=.546	F (5.42, 157.23)=1.21, p=.308

*Appendix Table 2.*9: shows non-significant interactions between evaluative conditioning measures (pleasantness, anxiety) by awareness by PCG classification and stimuli by awareness by PCG classifications interaction

	Cue						Goal					
	CS10		CS50		CS90		goal10		goal50		goal90	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Fixation count												
Aware												
Block 1	1.14	0.10	1.13	0.10	1.24	0.10	0.90	0.11	0.87	0.10	0.77	0.11
Block 2	1.11	0.10	1.21	0.11	1.27	0.10	0.81	0.09	0.81	0.10	0.74	0.09
Block 3	1.12	0.11	1.17	0.12	1.28	0.11	0.95	0.09	0.86	0.09	0.80	0.09
Block 4	1.19	0.11	1.26	0.10	1.25	0.11	0.91	0.09	0.81	0.09	0.86	0.09
Block 5	1.28	0.13	1.33	0.13	1.29	0.13	0.88	0.11	0.88	0.10	0.78	0.11
Block 6	1.17	0.11	1.18	0.12	1.22	0.11	0.90	0.09	0.88	0.09	0.76	0.09
Unaware												
Block 1	0.73	0.14	0.92	0.13	0.81	0.13	0.94	0.15	0.84	0.14	0.75	0.14
Block 2	0.79	0.13	0.85	0.14	0.82	0.12	0.94	0.12	0.85	0.13	0.81	0.12
Block 3	0.88	0.15	0.94	0.15	0.87	0.15	0.69	0.12	0.61	0.11	0.70	0.12
Block 4	0.90	0.15	0.84	0.13	0.93	0.14	0.74	0.12	0.66	0.11	0.63	0.12
Block 5	0.78	0.17	0.83	0.16	0.81	0.16	0.95	0.14	0.83	0.13	0.90	0.14
Block 6	0.78	0.14	0.88	0.15	0.74	0.15	0.75	0.11	0.69	0.11	0.75	0.12
Dwell Time												
Aware												
Block 1	238.65	23.72	231.54	23.77	249.37	25.51	183.22	25.74	159.32	21.23	150.21	24.24
Block 2	221.04	25.53	260.41	27.34	264.01	21.85	151.99	19.87	152.61	23.37	137.51	17.76
Block 3	216.93	25.14	236.87	27.13	252.53	26.10	176.67	18.56	149.91	18.78	153.77	20.02
Block 4	229.64	28.74	253.88	25.93	244.85	23.27	171.99	21.73	164.31	21.13	169.49	20.69
Block 5	237.35	22.27	273.26	26.31	248.54	27.06	173.95	23.08	169.14	23.80	154.06	22.27
Block 6	222.13	19.98	223.49	25.32	234.26	22.70	179.10	19.48	165.99	19.04	148.64	20.11
Unaware												
Block 1	136.38	30.62	184.10	30.69	184.06	32.93	207.57	33.23	160.30	27.40	162.56	31.29
Block 2	162.31	32.96	197.19	35.30	172.46	28.21	213.49	25.65	194.31	30.16	163.98	22.93
Block 3	170.36	32.46	180.35	35.02	186.68	33.70	137.58	23.96	126.20	24.25	140.25	25.85

Block 4	198.24	37.11	183.40	33.48	188.93	30.04	168.04	28.05	133.68	27.28	138.71	26.71
Block 5	167.64	28.75	194.96	33.96	179.12	34.94	170.31	29.80	165.27	30.72	172.48	28.74
Block 6	132.37	25.79	178.71	32.69	162.84	29.30	154.43	25.15	136.88	24.58	152.23	25.97
Run Count												
Aware												
Block 1	0.75	0.06	0.74	0.06	0.82	0.05	0.66	0.07	0.61	0.06	0.55	0.07
Block 2	0.73	0.06	0.79	0.06	0.83	0.05	0.60	0.06	0.58	0.06	0.54	0.06
Block 3	0.72	0.06	0.73	0.06	0.77	0.05	0.69	0.06	0.63	0.06	0.58	0.06
Block 4	0.77	0.06	0.83	0.06	0.84	0.06	0.69	0.06	0.61	0.06	0.61	0.06
Block 5	0.82	0.06	0.83	0.06	0.84	0.06	0.65	0.06	0.65	0.06	0.60	0.06
Block 6	0.78	0.06	0.78	0.06	0.81	0.05	0.69	0.06	0.66	0.06	0.59	0.06
Unaware												
Block 1	0.47	0.08	0.52	0.07	0.50	0.07	0.54	0.08	0.50	0.08	0.46	0.09
Block 2	0.51	0.07	0.55	0.07	0.52	0.07	0.56	0.07	0.51	0.07	0.50	0.08
Block 3	0.53	0.08	0.55	0.08	0.51	0.07	0.46	0.08	0.41	0.07	0.45	0.08
Block 4	0.51	0.07	0.50	0.07	0.53	0.07	0.47	0.08	0.48	0.08	0.43	0.08
Block 5	0.49	0.08	0.50	0.08	0.49	0.08	0.57	0.08	0.53	0.08	0.57	0.08
Block 6	0.47	0.07	0.53	0.07	0.46	0.07	0.48	0.08	0.45	0.08	0.47	0.08

Appendix Table 2.10: shows the fixation count, dwell time, run count, latency and pupil change split by *image, contingency*, a*wareness* and *block*

Participant number	PCA index	Participant number	PCA index
12	-0.35	56	-0.25
13	-0.02	59	0.11
15	-0.70**	65	0.18
19	-0.03	66	-0.15
21	-0.38	68	-0.24
22	-0.33	76	0.24
25	0.12	77	0.40
26	0.10	79	0.17
31	0.01	80	-0.41
32	-0.14	82	0.01
36	0.01	86	0.04
38	-0.17	90	0.15
46	-0.25	94	-0.01
47	0.01	95	-0.05
48	-0.02	97	-0.02
51	0.06	130	-0.25

Appendix Table 2.11: shows PCA index for each participant in experiment 2, calculated using *dwell time* the 3 *blocks* of training. **denotes participant whose PCA index score allows for classification.

Grouping variables	Goal-Tracker	Intermediate	Sign-Tracker	total
PCG class	11	18	3	32
Sex:				
Male:	4	11	2	17
female	7	7	1	15
Smoker:				
Smoker:	5	1	0	6
Non-smoker:	6	17	3	26
Awareness:				
Aware:	5	12	1	18
Unaware:	6	6	2	14
Binge class.				
Binger:	3	1	7	11
Non-Binger:	4	1	5	10*
Poly drug class.				
Poly-drug	4	11	0	15
Mono-drug/ Drug naïve	7	7	3	17

Appendix Table 2.11: shows distribution of grouping variables across levels of Pavlovian Conditioned Gaze classification. * Participants with an "unclassifiable" binge score were not included in the analysis (Experiment 2)

Behavioural measure	**Main effect of *Contingency***
Fixation count	$t(31)= -.32$, $p=.748$
Run Count	$t(31)= -1.76$, $p=.088$
% Change in pupil dilation	$t(31)= 1.03$, $p=.313$

Appendix Table 2.12: shows the effect of *contingency* alone across eye-tracking measures (Experiment 2)

Behavioural measure	**Interaction between *Awareness* and *PCG classification***
Fixation count	$t\ (31) = -0.32$, $p = .748$
Dwell time	$t\ (31) = 2.03$, $p = .051$
% Change in pupil dilation	$t\ (31) = 1.51$, $p = .142$
Run Count	$t\ (31) = -1.76$, $p = .088$

Appendix Table 2.13: shows the effect of awareness across *PCG classification* (Experiment 2)

Behavioural measure	**Interaction between *Awareness, PCG classification* and *contingency***
Fixation count	$F\ (2,26) = 1.01$, $p = .379$
Dwell time	$F\ (2,26) = 1.07$, $p = .357$
Run Count	$F\ (2,26) = 0.10$, $p = .905$
Latency	$F\ (2,26) = 0.08$, $p = .928$
% pupil change	$F\ (2,26) = 0.19$, $p = .822$

Appendix Table 2.14: shows the effect of awareness across *contingencies* between *PCG classification* on total fixation count, dwell time, latency and run count

Behavioural measure	**Interaction between *Awareness, PCG classification, contingency* and *image***
Fixation count	$F(2,26) = 0.32$, $p = .731$
Dwell time	$F(2,26) = 0.61$, $p = .550$
Run Count	$F(2,26) = 0.43$, $p = .653$
Latency	$F(2,26) = 0.77$, $p = .474$
% pupil change	$F(2,26) = 0.24$, $p = .792$

Appendix Table 2.15: shows the effect of awareness across *contingencies* between *PCG classification* on total fixation count, dwell time, latency and run count

	awareness by PCG classification	***Contingency by image awareness by PCG classification***
pleasantness	$F(2, 26)=0.66$, $p=.526$	$F(2, 26)=0.75$, $p=.484$
anxiety	$F(2, 26)=1.61$, $p=.219$	$F(2, 26)=1.94$, $p=.164$

***Appendix Table 2.16*:** shows non-significant interactions between evaluative conditioning measures (pleasantness, anxiety) by awareness by PCG classification and stimuli by awareness by PCG classifications interaction

	Aware				Unaware			
	CS0		CS50		CS0		CS50	
	M	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***
Fixation count								
Goal-Tracker	0.90	0.13	0.92	0.15	0.91	0.15	0.88	0.16
Intermediate	0.95	0.12	0.93	0.13	0.79	0.10	0.79	0.12
Sign-Tracker	0.89	0.33	0.70	0.37	1.04	0.23	1.09	0.26
Dwell Time								
Goal-Tracker	258.69	35.41	275.76	37.60	214.77	38.79	231.79	41.19
Intermediate	230.24	30.67	239.02	32.56	201.89	27.43	207.25	29.12
Sign-Tracker	257.57	86.74	336.89	92.10	256.28	61.34	265.83	65.12
Latency								
Goal-Tracker	822.61	116.83	794.36	117.58	932.07	127.98	883.06	128.81
Intermediate	890.34	101.18	853.75	101.83	833.46	90.49	798.92	91.08
Sign-Tracker	878.30	286.17	838.73	288.02	1050.73	202.35	978.39	203.66
Run Count								
Goal-Tracker	0.64	0.10	0.60	0.10	0.67	0.11	0.64	0.11
Intermediate	0.68	0.09	0.68	0.09	0.61	0.08	0.59	0.08
Sign-Tracker	0.60	0.24	0.59	0.24	0.71	0.17	0.69	0.17
Pupil change								
Goal-Tracker	1.22	5.88	45.82	23.02	4.77	6.45	41.11	25.22
Intermediate	0.52	5.10	-4.36	19.94	9.75	4.56	17.65	17.83
Sign-Tracker	-5.55	14.41	-4.61	56.40	2.89	10.19	-15.93	39.88

Table 2.17: shows the fixation count, dwell time, run count, latency and pupil change split by *awareness, contingency* and *PCG classifications. Aware goal-trackers N=6, unaware goal-trackers N=5, aware intermediates N=8, unaware intermediates N=10, aware sign-trackers N=1, unaware sign-trackers N=2.*

	Cue				Goal			
	CS0		CS50		Goal0		Goal50	
	M	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***
Fixation count								
Aware								
Goal-Tracker	0.60	0.16	0.48	0.15	1.19	0.17	1.36	0.21
Intermediate	1.08	0.13	0.98	0.13	0.82	0.15	0.89	0.18
Sign-Tracker	0.90	0.38	0.83	0.37	0.88	0.42	0.57	0.52
Unaware								
Goal-Tracker	0.67	0.17	0.48	0.17	1.13	0.19	1.28	0.23
Intermediate	0.78	0.12	0.82	0.12	0.81	0.13	0.77	0.16
Sign-Tracker	1.35	0.27	1.36	0.26	0.75	0.29	0.81	0.37
Dwell Time								
Aware								
Goal-Tracker	156.88	42.78	130.52	46.01	360.57	49.15	419.51	46.62
Intermediate	274.04	37.05	260.07	39.85	188.10	42.57	217.38	40.37
Sign-Tracker	304.65	104.79	456.95	112.70	210.48	120.39	216.83	114.19
Unaware								
Goal-Tracker	144.37	46.86	109.13	50.40	282.11	53.84	353.57	51.07
Intermediate	212.72	33.14	238.41	35.64	190.82	38.07	178.43	36.11
Sign-Tracker	390.24	74.10	380.55	79.69	125.33	85.13	150.27	80.74
Latency								
Aware								
Goal-Tracker	676.12	134.08	565.12	138.59	970.29	132.02	1023.14	132.73
Intermediate	950.66	116.12	898.13	120.02	834.02	114.33	806.52	114.95
Sign-Tracker	814.98	328.43	975.85	339.46	941.62	323.38	701.60	325.12
Unaware								
Goal-Tracker	870.98	146.88	634.52	151.81	984.17	144.62	1137.74	145.40
Intermediate	845.75	103.86	849.86	107.35	817.65	102.26	750.46	102.81
Sign-Tracker	1218.97	232.24	1050.08	240.04	899.40	228.66	904.18	229.90

Run Count								
Aware								
Goal-Tracker	0.46	0.10	0.39	0.10	0.81	0.12	0.82	0.12
Intermediate	0.73	0.09	0.71	0.09	0.64	0.10	0.65	0.11
Sign-Tracker	0.60	0.25	0.72	0.25	0.60	0.29	0.47	0.30
Unaware								
Goal-Tracker	0.54	0.11	0.40	0.11	0.79	0.13	0.87	0.13
Intermediate	0.61	0.08	0.59	0.08	0.62	0.09	0.59	0.09
Sign-Tracker	0.88	0.18	0.83	0.18	0.56	0.21	0.56	0.21
Pupil change								
Aware								
Goal-Tracker	-23.37	9.32	-47.91	18.23	68.10	28.09	161.52	59.47
Intermediate	8.30	8.07	24.61	15.79	-8.32	24.33	-4.49	51.50
Sign-Tracker	-2.80	22.83	21.38	44.66	5.76	68.82	-30.31	145.66
Unaware								
Goal-Tracker	-13.50	10.21	-38.47	19.97	43.93	30.78	183.40	65.14
Intermediate	-2.74	7.22	3.00	14.12	27.28	21.76	-10.54	46.06
Sign-Tracker	22.94	16.14	50.31	31.58	-33.09	48.66	-23.53	103.00

Table 2.18: shows the fixation count, dwell time, run count, latency and pupil change split by *awareness, contingency* and *PCG classifications. Aware goal-trackers N=6, unaware goal-trackers N=5, aware intermediates N=8, unaware intermediates N=10, aware sign-trackers N=1, unaware sign-trackers N=2.*

	Cue				Goal			
	CS0		CS50		Goal0		Goal50	
	M	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***
Fixation count								
Aware								
Block 1	0.77	0.14	0.68	0.13	1.06	0.11	1.10	0.13
Block 2	0.69	0.11	0.64	0.14	1.06	0.13	1.14	0.16
Block 3	0.83	0.12	0.64	0.11	0.99	0.12	1.14	0.15
Unaware								
Block 1	1.07	0.13	1.01	0.12	0.84	0.10	0.86	0.12
Block 2	0.82	0.11	0.79	0.13	0.81	0.12	0.85	0.15
Block 3	0.87	0.11	0.85	0.11	0.87	0.12	0.86	0.14
Dwell Time								
Aware								
Block 1	182.75	36.16	186.63	40.50	272.17	37.15	290.66	42.20
Block 2	161.07	32.81	192.93	43.14	255.47	41.02	303.54	40.80
Block 3	222.07	37.27	187.49	36.82	258.03	38.05	290.91	39.80
Unaware								
Block 1	281.81	33.97	278.81	38.05	216.17	34.90	233.44	39.64
Block 2	223.50	30.82	220.14	40.52	199.20	38.53	219.44	38.32
Block 3	242.61	35.01	238.03	34.58	205.32	35.74	234.69	37.39
Latency								
Aware								
Block 1	815.39	91.20	718.77	104.76	1019.12	80.53	922.05	86.39
Block 2	770.25	101.09	639.21	109.19	910.22	91.89	990.23	98.06
Block 3	845.08	103.13	728.63	99.28	920.09	98.79	990.43	104.72
Unaware								
Block 1	986.27	85.66	973.07	98.41	842.09	75.64	824.39	81.15
Block 2	873.27	94.96	792.69	102.57	851.86	86.32	808.06	92.11
Block 3	888.69	96.87	861.87	93.26	792.98	92.79	795.07	98.37

Run Count								
Aware								
Block 1	0.56	0.08	0.51	0.08	0.75	0.07	0.69	0.07
Block 2	0.53	0.07	0.48	0.09	0.73	0.08	0.75	0.09
Block 3	0.59	0.08	0.51	0.07	0.74	0.09	0.74	0.10
Unaware								
Block 1	0.73	0.07	0.71	0.08	0.63	0.06	0.64	0.07
Block 2	0.61	0.07	0.59	0.08	0.62	0.08	0.62	0.08
Block 3	0.66	0.08	0.61	0.07	0.65	0.08	0.67	0.09
% Pupil change								
Aware								
Block 1	20	15	-22	17	-13	16	-19	18
Block 2	34	20	-34	21	-14	17	-23	18
Block 3	18	17	-26	20	-1	17	-20	17
Unaware								
Block 1	-7	14	-8	14	0	14	3	16
Block 2	-10	15	5	15	-2	17	-19	14
Block 3	-11	15	-1	15	-3	16	-6	15

Table 2.19: shows the fixation count, dwell time, run count, latency and pupil change split by *awareness, contingency* and *PCG classifications. Aware goal-trackers N=6, unaware goal-trackers N=5, aware intermediates N=8, unaware intermediates N=10, aware sign-trackers N=1, unaware sign-trackers N=2.*

Participant number	PCA index	Participant number	PCA index
1187	0.37	4426	-0.03
1296	0.18	4428	0.47
1350	0.02	4633	0.45
1606	-0.13	5184	0.27
1923	-0.10	5836	0.09
2475	0.19	7137	0.19
2651	0.14	7171	0.33
3257	0.44	7350	0.17
3397	0.03	7651	0.52**
3649	-0.10	7674	-0.01
3899	-0.03	7946	-0.08
3957	0.05	8323	0.35
4053	0.10	8687	-0.14
4185	-0.09		

Appendix Table 2.20: shows PCA index for each participant in experiment 3, calculated using *dwell time* the 3 *blocks* of training. **denotes participant whose PCA index score allows for classification.

Grouping variables	Goal-Tracker	Intermediate	Sign-Tracker	total
PCG class	6	18	5	29
Sex:				
Male:	1	12	0	13
female	5	6	5	16
Smoker:				
Smoker:	0	2	0	2
Non-smoker:	6	15	4	25*
Awareness:				
Aware:	3	9	3	15
Unaware:	3	9	2	14
Binge class.				
Binger:	0	8	2	10
Non-Binger:	1	4	1	6**
Poly drug class.				
Poly-drug	3	8	1	12
Mono-drug/ Drug naïve	3	10	4	17

Appendix Table 2.21: shows distribution of grouping variables across levels of Pavlovian Conditioned Gaze classification.* some participants did not report smoking behaviour, ** Participants with an "unclassifiable" binge score were not included in the analysis (Experiment 3)

Behavioural measure	**Main effect of *Contingency***
Fixation count	F (2,56) = 1.77, p =.179
Percentage Pupil change	F (1.09, 30.53) = 2.93, p =.094
Latency	F (1.42, 39.82) = 0.61, p =.493
Run Count	F (1.44, 40.38) = 0.14, p =.802

Appendix Table 2.22: shows the effect of *contingency* alone across eye-tracking measures (Experiment 3)

Behavioural measure	**Interaction between *Awareness* and *PCG classification***
Fixation count	F (1.22, 33.03) = 1.35, p =.262
Dwell time	F (1.13, 30.49) = 0.41, p =.552
Latency	F (1.64, 44.36) = 0.77, p =.447
Run Count	F (1.42, 38.45) = 0.81, p =.416
Percentage pupil change	F (1.51, 40.71) = 0.37, p =.637

Appendix Table 2.23: shows the effect of awareness across *PCG classification*, (Experiment 3)

Behavioural measure	**Interaction between *Awareness, PCG classification* and *contingency***
Fixation count	F (4,46) = 0.76, p =.558
Dwell time	F (4,46) = 1.22, p =.317
Run Count	F (2.67, 30.75) = 0.66, p =.567
Latency	F (2.98, 34.25) = 0.33, p =.806
% pupil change	F (2.22,25.49) = 0.04, p =.968

Appendix Table 2.24: shows the effect of awareness across *contingencies* between *PCG classification* on total fixation count, dwell time, latency and run count (Experiment 3; *M*s and *SE*s in table 16A)

Behavioural measure	**Interaction between *Awareness, PCG classification, contingency* and *image***
Fixation count	F (4, 46) = 0.99, p =.425
Dwell time	F (4, 46) = 0.87, p =.492
Run Count	F (4, 46) = 1.87, p =.132
Latency	F (4, 46) = 1.71, p =.164
% pupil change	F (4, 46) = 0.79, p =.533

Appendix Table 2.25: shows the effect of awareness across *contingencies* between *PCG classification* on total fixation count, dwell time, latency and run count (Experiment 3; *M*s and *SE*s in table 16B)

	awareness by PCG classification	***stimuli by awareness by PCG classification***
pleasantness	F (2, 22)=3.28, p=.057	F (5.89, 64.83)=1.21, p=.312
anxiety	F (2, 22)=1.49, p=.247	F (6,66)=0.47, p=.825

Appendix Table 2.26: shows non-significant interactions between evaluative conditioning measures (pleasantness, anxiety) by awareness by PCG classification and stimuli by awareness by PCG classifications interaction

	Aware						Unaware					
	CS10		CS50		CS90		CS10		CS50		CS90	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Fixation count												
Goal-Tracker	1.61	0.44	1.80	0.45	1.98	0.45	2.14	0.44	2.18	0.45	2.44	0.45
Intermediate	1.81	0.25	1.83	0.26	1.79	0.26	2.35	0.25	2.52	0.26	2.42	0.26
Sign-Tracker	2.89	0.44	2.78	0.45	2.79	0.45	2.31	0.53	2.65	0.55	2.41	0.56
Dwell Time												
Goal-Tracker	953.93	171.44	996.28	159.56	1053.11	169.61	1140.59	171.44	1022.11	159.56	1100.03	169.61
Intermediate	1040.78	98.98	984.21	92.12	1052.02	97.92	961.78	98.98	934.59	92.12	970.87	97.92
Sign-Tracker	946.07	171.44	860.95	159.56	975.26	169.61	1018.51	209.97	997.17	195.42	1062.38	207.73
Latency												
Goal-Tracker	1781.87	111.28	1751.98	120.29	1756.38	114.12	1547.87	111.28	1624.13	120.29	1546.06	114.12
Intermediate	1759.05	64.25	1722.79	69.45	1780.10	65.88	1752.67	64.25	1787.04	69.45	1767.76	65.88
Sign-Tracker	1815.38	111.28	1708.39	120.29	1835.99	114.12	1880.09	136.29	1701.24	147.32	1854.67	139.76
Run Count												
Goal-Tracker	0.79	0.20	0.79	0.20	0.87	0.21	0.90	0.20	0.93	0.20	1.02	0.21
Intermediate	1.02	0.11	1.02	0.11	0.99	0.12	1.22	0.11	1.22	0.11	1.24	0.12
Sign-Tracker	1.24	0.20	1.11	0.20	1.16	0.21	1.22	0.24	1.32	0.24	1.25	0.25
Pupil change												
Goal-Tracker	-2.36	2.50	1.27	0.65	0.76	2.47	-1.79	2.50	1.74	0.65	0.25	2.47
Intermediate	-2.28	1.45	1.64	0.37	0.69	1.42	-0.65	1.45	1.31	0.37	-0.98	1.42
Sign-Tracker	2.60	2.50	2.34	0.65	-4.44	2.47	3.98	3.07	2.31	0.79	-6.11	3.02

Table 3.27: shows the fixation count, dwell time, run count, latency and pupil change split by *awareness, contingency* and *PCG classifications. Aware goal-trackers N=3, unaware goal-trackers N=3, aware intermediates N=9, unaware intermediates N=9, aware sign-trackers N=3, unaware sign-trackers N=2.*

	Cue						Goal					
	CS10		CS50		CS90		goal10		goal50		goal90	
	M	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***	***M***	***SE***
Fixation count												
Aware												
Goal-Tracker	0.69	0.68	0.64	0.66	0.83	0.51	2.53	0.41	2.95	0.41	3.13	0.52
Intermediate	2.11	0.39	2.10	0.38	1.93	0.29	1.51	0.24	1.56	0.24	1.65	0.30
Sign-Tracker	4.74	0.68	4.89	0.66	4.43	0.51	1.03	0.41	0.68	0.41	1.14	0.52
Unaware												
Goal-Tracker	0.87	0.68	0.92	0.66	1.13	0.51	3.42	0.41	3.43	0.41	3.74	0.52
Intermediate	2.75	0.39	2.65	0.38	2.06	0.29	1.95	0.24	2.39	0.24	2.77	0.30
Sign-Tracker	3.08	0.83	3.66	0.81	3.28	0.62	1.54	0.51	1.65	0.50	1.54	0.64
Dwell Time												
Aware												
Goal-Tracker	291.93	227.22	235.16	194.27	249.98	189.57	1615.93	226.74	1757.41	224.45	1856.23	238.04
Intermediate	1133.68	131.18	992.95	112.16	1026.85	109.45	947.88	130.91	975.47	129.58	1077.19	137.44
Sign-Tracker	1581.93	227.22	1531.75	194.27	1604.72	189.57	310.22	226.74	190.15	224.45	345.81	238.04
Unaware												
Goal-Tracker	298.83	227.22	301.96	194.27	391.61	189.57	1982.35	226.74	1742.27	224.45	1808.46	238.04
Intermediate	1084.79	131.18	937.24	112.16	791.36	109.45	838.78	130.91	931.94	129.58	1150.39	137.44

Sign-Tracker	1433.53	278.28	1396.61	237.93	1546.72	232.18	603. 49	277.70	597.73	274.89	578.05	291.54
Latency												
Aware												
Goal-Tracker	1736.17	110.81	1820.41	152.63	1773.25	100.20	1796.17	165.94	1744.77	151.63	1763.97	188.90
Intermediate	1538.11	63.97	1438.64	88.12	1524.39	57.85	2011.17	95.81	2080.00	87.55	2054.27	109.06
Sign-Tracker	1350.53	110.81	1320.28	152.63	1327.56	100.20	2656.00	165.94	2906.53	151.63	2694.63	188.90
Unaware												
Goal-Tracker	1510.01	110.81	1432.93	152.63	1496.58	100.20	1576.17	165.94	1701.77	151.63	1568.76	188.90
Intermediate	1480.29	63.97	1493.75	88.12	1516.28	57.85	2027.99	95.81	2102.12	87.55	2015.58	109.06
Sign-Tracker	1483.20	135.71	1279.33	186.93	1388.35	122.72	2450.25	203.24	2266.57	185.71	2461.47	231.35
Run Count												
Aware												
Goal-Tracker	0.48	0.22	0.37	0.24	0.52	0.22	1.10	0.20	1.22	0.20	1.21	0.22
Intermediate	1.11	0.13	1.16	0.14	1.07	0.12	0.92	0.12	0.89	0.12	0.92	0.13
Sign-Tracker	1.79	0.22	1.81	0.24	1.61	0.22	0.69	0.20	0.41	0.20	0.71	0.22
Unaware												
Goal-Tracker	0.57	0.22	0.56	0.24	0.70	0.22	1.23	0.20	1.30	0.20	1.33	0.22
Intermediate	1.37	0.13	1.29	0.14	1.19	0.12	1.06	0.12	1.14	0.12	1.29	0.13
Sign-Tracker	1.53	0.28	1.59	0.30	1.56	0.26	0.91	0.25	1.05	0.25	0.95	0.27
Pupil change												

Aware												
Goal-Tracker	-1.18	2.74	-0.58	2.68	-0.22	2.61	4.62	3.73	0.68	2.56	0.72	3.53
Intermediate	-3.45	1.58	-0.19	1.55	-1.39	1.50	4.58	2.16	0.26	1.48	2.71	2.04
Sign-Tracker	-10.18	2.74	-0.08	2.68	-7.94	2.61	1.92	3.73	0.10	2.56	1.86	3.53
Unaware												
Goal-Tracker	-4.00	2.74	-0.83	2.68	-2.61	2.61	7.68	3.73	1.21	2.56	2.85	3.53
Intermediate	-2.38	1.58	0.06	1.55	-3.97	1.50	4.63	2.16	0.23	1.48	1.92	2.04
Sign-Tracker	-4.35	3.35	0.64	3.28	-8.89	3.19	-4.10	4.57	-0.60	3.13	-2.47	4.33

Table 3.28: shows the fixation count, dwell time, run count, latency and pupil change split by *awareness, contingency* and *PCG classifications. Aware goal-trackers N=3, unaware goal-trackers N=3, aware intermediates N=9, unaware intermediates N=9, aware sign-trackers N=3, unaware sign-trackers N=2.*

	Cue						Goal					
	CS10		CS50		CS90		goal10		goal50		goal90	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Fixation count												
Aware												
Block 1	0.25	1.66	0.29	1.73	0.34	2.35	0.45	2.03	0.38	2.20	0.35	0.25
Block 2	0.29	1.88	0.28	2.17	0.33	2.27	0.47	2.07	0.49	1.97	0.41	0.29
Block 3	0.32	1.55	0.33	1.56	0.34	2.36	0.42	2.41	0.47	2.27	0.37	0.32
Block 4	0.26	1.51	0.29	1.70	0.31	2.73	0.44	2.76	0.44	2.49	0.35	0.26
Block 5	0.26	1.60	0.26	1.87	0.30	2.22	0.45	2.41	0.46	2.11	0.44	0.26
Block 6	0.29	1.84	0.33	1.96	0.33	2.24	0.43	2.43	0.50	2.27	0.36	0.29
Unaware												
Block 1	0.26	2.34	0.30	2.63	0.35	2.52	0.47	2.46	0.39	2.09	0.36	0.26
Block 2	0.30	2.58	0.29	2.85	0.34	2.00	0.48	2.25	0.50	1.88	0.42	0.30
Block 3	0.33	2.67	0.34	3.22	0.35	2.51	0.43	2.66	0.49	1.97	0.39	0.33
Block 4	0.27	2.30	0.30	2.50	0.32	2.65	0.45	2.72	0.46	2.27	0.36	0.27
Block 5	0.27	2.15	0.27	2.77	0.31	2.20	0.47	2.28	0.48	1.95	0.46	0.27
Block 6	0.30	3.07	0.34	2.95	0.35	2.35	0.44	2.20	0.51	2.05	0.37	0.30
Dwell Time												
Aware												
Block 1	897.97	168.20	958.22	174.70	1037.88	181.32	1128.31	163.61	926.68	153.92	1033.36	168.04
Block 2	1139.22	190.40	1071.72	182.04	1279.40	194.55	885.90	173.06	800.52	149.52	800.14	156.80
Block 3	865.52	171.13	899.04	170.88	924.29	184.52	1089.53	153.92	1065.48	154.71	1062.35	155.96
Block 4	830.88	155.27	878.83	157.78	985.51	161.32	1108.14	156.48	1009.85	160.86	1107.61	151.14
Block 5	1003.02	184.18	981.64	158.55	1124.21	190.02	1005.35	176.97	900.78	141.41	873.59	164.51
Block 6	1022.05	170.51	1130.61	188.53	1075.88	156.18	1071.34	161.24	942.99	175.49	1109.03	155.88
Unaware												
Block 1	1082.98	174.11	1056.13	180.83	1118.25	187.69	989.73	169.35	899.91	159.33	919.00	173.94
Block 2	1125.52	197.08	1140.72	188.43	1310.60	201.38	864.13	179.14	750.61	154.76	758.85	162.30
Block 3	1021.79	177.14	1002.43	176.88	1268.47	191.00	1008.06	159.32	888.84	160.14	730.44	161.43
Block 4	934.84	160.72	913.30	163.32	1107.58	166.99	946.46	161.97	1002.07	166.51	927.59	156.45

Block 5	1002.23	190.65	969.99	164.11	1251.29	196.69	1030.40	183.18	879.56	146.37	720.07	170.28
Block 6	1168.61	176.49	1284.07	195.14	1251.27	161.66	915.93	166.90	775.58	181.65	781.76	161.36

Run Count

Aware

Block 1	0.89	0.11	0.89	0.12	0.92	0.13	1.11	0.15	1.02	0.15	1.04	0.14
Block 2	0.95	0.10	0.86	0.12	1.01	0.10	1.06	0.19	1.11	0.19	0.94	0.17
Block 3	0.90	0.13	0.74	0.15	0.87	0.14	1.13	0.19	1.23	0.20	1.13	0.16
Block 4	0.91	0.13	0.85	0.13	0.93	0.13	1.27	0.16	1.22	0.15	1.18	0.14
Block 5	1.00	0.12	0.93	0.11	0.97	0.11	1.11	0.16	1.18	0.17	1.00	0.16
Block 6	0.84	0.10	0.90	0.11	0.89	0.10	1.07	0.14	1.04	0.18	1.11	0.14

Unaware

Block 1	1.05	0.11	1.05	0.12	1.22	0.14	1.21	0.16	1.23	0.15	1.16	0.15
Block 2	1.08	0.11	1.18	0.12	1.31	0.10	1.09	0.20	1.03	0.20	1.05	0.17
Block 3	1.23	0.14	1.38	0.15	1.39	0.14	1.34	0.19	1.36	0.21	1.16	0.17
Block 4	1.05	0.13	1.16	0.13	1.22	0.14	1.28	0.16	1.27	0.16	1.25	0.14
Block 5	0.96	0.12	1.00	0.11	1.18	0.11	1.14	0.16	1.11	0.17	1.07	0.16
Block 6	1.11	0.11	1.25	0.11	1.20	0.10	1.26	0.15	1.09	0.18	1.12	0.14

Latency

Aware

Block 1	2087.79	161.27	2053.34	130.39	2092.84	160.42	1471.59	95.31	1375.71	132.07	1443.26	133.27
Block 2	2165.46	146.03	2334.71	151.69	2130.32	147.86	1496.01	147.03	1443.92	143.82	1288.96	133.19
Block 3	2075.80	172.92	2146.21	109.36	2191.00	156.19	1411.05	115.21	1397.77	154.11	1410.51	119.05
Block 4	2159.36	101.38	2274.86	166.51	2265.20	164.52	1527.99	72.10	1449.28	158.08	1494.53	91.01
Block 5	2020.39	115.10	2163.13	121.52	2135.14	130.88	1526.66	48.49	1496.71	86.12	1563.52	102.67
Block 6	2125.21	123.22	1935.91	171.04	2100.77	120.57	1516.73	75.52	1380.63	97.21	1583.43	89.32

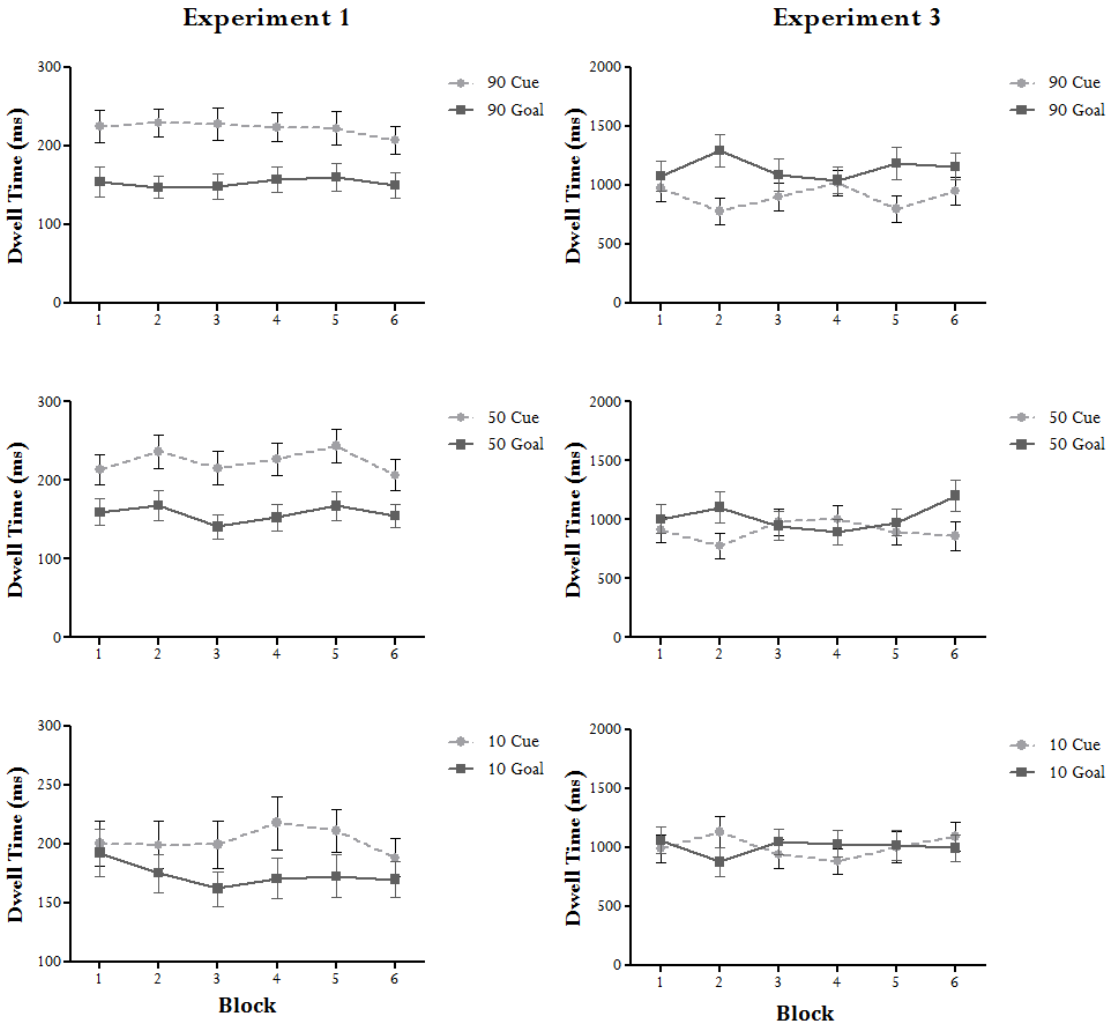
Unaware

Block 1	1835.63	166.93	2079.07	134.96	2063.21	166.05	1422.59	98.66	1386.18	136.70	1232.54	137.95
Block 2	1938.35	151.16	2063.22	157.02	1984.01	153.05	1448.41	152.19	1169.34	148.87	1379.18	137.86
Block 3	1875.81	178.99	1955.80	113.20	1935.50	161.67	1368.56	119.26	1130.65	159.51	1391.39	123.22
Block 4	2062.78	104.93	2295.90	172.35	1858.46	170.29	1485.82	74.63	1487.61	163.62	1357.30	94.21
Block 5	1993.43	119.14	1976.94	125.78	1995.21	135.48	1456.54	50.20	1430.94	89.14	1382.92	106.27
Block 6	2077.46	127.54	1964.68	177.05	1989.77	124.80	1566.32	78.17	1443.76	100.62	1543.24	92.45

% Pupil change

Aware												
Block 1	16.19	23.37	19.36	23.96	14.06	22.25	-8.51	17.96	-0.14	19.96	-7.80	19.08
Block 2	16.30	24.17	19.93	26.04	16.15	23.00	-8.46	19.65	-6.64	21.51	-15.85	19.66
Block 3	17.55	25.55	25.81	28.24	15.55	22.81	-7.41	18.93	-8.56	20.29	-12.14	17.90
Block 4	14.72	23.55	17.31	24.49	13.96	22.99	-1.04	17.89	3.58	19.50	1.03	18.75
Block 5	11.12	23.48	15.23	24.24	10.84	21.25	-3.99	17.68	0.88	19.08	-2.45	18.02
Block 6	15.56	24.03	15.33	26.10	11.85	22.35	-0.10	18.33	-7.21	19.93	-3.14	17.72
Unaware												
Block 1	-13.55	19.76	1.43	20.25	2.23	18.81	-18.85	14.12	-19.27	15.68	-29.63	14.99
Block 2	11.10	22.49	13.88	24.22	11.54	21.40	-20.99	15.41	-24.64	16.86	-19.84	15.42
Block 3	-10.66	21.68	-2.61	23.96	1.30	19.36	-17.18	15.60	-24.46	16.73	-23.47	14.75
Block 4	-0.03	21.16	-4.08	22.00	-8.74	20.66	-12.15	15.40	-18.34	16.79	-19.97	16.14
Block 5	4.39	21.23	-0.09	21.91	-1.42	19.21	-9.52	15.71	-6.73	16.95	-13.42	16.01
Block 6	2.74	20.54	4.33	22.32	2.39	19.11	-15.38	14.88	-14.58	16.19	-14.13	14.39

Table 3.28: shows the fixation count, dwell time, run count, latency and pupil change split by *awareness, contingency* and *block. Aware N=15, unaware N=14*



Appendix Figure 2.1: a post hoc examination of the dwell times on the goal and cue across blocks showed that in experiment 4.1 participants showed a biased towards the cue image, irrespective of reward contingency. Conversely, in experiment 3 at 10 and 50% probability, dwell times on the cue and goal were the same across blocks, i.e. across time. At 90%, dwell times were biased towards the goal across blocks

Appendix 3: probability- and delay-discounting in humans

	Prime	Devaluation
SS RT	$F(2,62)=0.45$, $p=.640$	$t(63)=0.72$, $p=.472$
SS go correct	$F(2,62)=1.16$, $p=.321$	$t(63)=-0.07$, $p=.946$
SS go latency	$F(2,37.80)=2.79$, $p=.074$	$t(63)=1.17$, $p=.247$

Table A3.1: shows results of ANOVAs comparing results of stop signal analysis across levels of prime (speed, accuracy and control) and Devaluation (devalued and maintained) in experiment 6.3

4.1: priming materials

Today's study consists of a number of computerised tasks that you will have to complete. Before you begin you are going to complete a memory task. I am now going to read a short story and at the end of the study I will ask you to repeat as many details of the story as you can, so please try to remember it. When I am reading the story to you I would like you to try to put yourself into the character's shoes. In a way, I want you to imagine that you are that character, even if they do not behave the way that you are used to.

Female passages

Speed condition

Jane has always been a woman who makes up her mind quickly, and who rushes through life; this has resulted in an extremely successful career and a happy personal life. She has a tendency to act without thinking, and on impulse, and seems to never sit still. She does everything in a rush without stopping to breath, and has been extremely successful because of this. As a young woman, before going to university Jane took a gap year unexpectedly. She had been accepted into a university but decided at the last minute to join a friend who was spending 6 months travelling around South America and Australia. Jane loved the six months away: meeting new people and visiting amazing places. After returning from her gap year Jane spent the next three years at university, graduating with a First. After university Jane went on to have a very successful career, earning a reputation as being an intuitive, intelligent and impulsive woman who gets results. In addition to her career, Jane has a very content personal life. She remains happily married after meeting her husband whilst on an unplanned holiday with friends. She is popular among her

friends, where she has a reputation for being fun and carefree company. Even now, at retiring age she has a tendency to act on impulse and race through life. When she was younger friends would sometimes tell her to slow down, but she is glad she didn't – if she had she wouldn't have achieved all she has done in her life.

Accuracy condition

Jane has always been a steady woman who makes up her mind in a careful and thoughtful manner; this has resulted in an extremely successful career and a happy personal life. She has a tendency to think through her actions very carefully, rarely acts on impulse, and has high self-control. She does everything conscientiously, and has been extremely successful because of this. As a young woman, before going to university Jane took a gap year. During her gap year she found a full time job and worked hard, allowing her to save enough money to visit South Africa. The year also allowed her more time to research universities, and seek out career advice, resulting in a very happy three years at a top university and a First. After university Jane went on to have a highly successful career, earning a reputation among her peers as being a conscientious and intelligent woman who does not rush to judgment and so gets results. In addition to her career, Jane has a very content personal life. She remains happily married after meeting her husband at work, and is popular among her friends, where she has a reputation for being kind and considerate, as well as dependable. Even now, at retiring age she is known to be reliable and reluctant to make a quick judgment. When she was younger friends would sometimes tell her to lighten up, but she is glad she didn't – if she had she wouldn't have achieved all she has done in her life.

Control condition

Jane has always been a kind and friendly woman; this has resulted in an extremely successful career and a happy personal life. As a young woman, before going to university Jane took a gap year. This gave her time to earn money to travel to South Africa for six months. Jane loved the six months away: meeting new people and visiting amazing places. After returning from her gap year Jane spent the next three years at university, graduating with a First. She then went on to have a highly successful career, earning a good reputation among her peers. In addition to her career, Jane has a very content personal life. She remains happily married after meeting her husband at the age of 27, and is popular among her friends. Even now, at retiring age she has a large group of friends, and is a member of a number of clubs and regularly frequents social events. Jane feels she has achieved a lot in her life.

Male passages

Speed condition

John has always been a man who makes up his mind quickly, and who rushes through life; this has resulted in an extremely successful career and a happy personal life. He has a tendency to act without thinking, and on impulse, and seems to never sit still. He does everything in a rush without stopping to breath, and has been extremely successful because of this. As a young man, before going to university John took a gap year unexpectedly. He had been accepted into a university but decided at the last minute to join a friend who was spending 6 months travelling around South America and Australia. John loved the six months away: meeting new people and visiting amazing places. After returning from his gap year John spent the next three years at university, graduating with a First. After university John went on to have a very successful career, earning a reputation as being an intuitive, intelligent and impulsive man who gets results. In addition to his career, John has a very content personal life. He remains happily married after meeting his husband whilst on an unplanned holiday with friends. He is popular among his friends, where he has a reputation for being fun and carefree company. Even now, at retiring age he has a tendency to act on impulse and race through life. When he was younger friends would sometimes tell him to slow down, but he is glad he didn't – if he had he wouldn't have achieved all he has done in his life.

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