

**Decision Making Under Uncertainty: Differentiating Between ‘*If*’,
‘*What*’ and ‘*When*’ Outcomes Occur**

A thesis submitted to The University of Manchester for the degree of
Doctor of Philosophy in the Faculty of Medical and Human Sciences

2012

Marianna Blackburn

School of Psychological Sciences

“We know a lot about how people make decisions about simple lotteries, but we know remarkably little about decision under uncertainty, possibly because we have not had a good laboratory model of uncertainty”.

Lisa Lopes, 1983 p. 138

Contents

List of Tables	11
Abstract	12
Declaration	13
Copyright Statement	14
Acknowledgements.....	15
List of Abbreviations.....	16
The Author	17
Publications and Conference Presentations	17
Thesis Background: the bigger picture	19
CHAPTER 1: General Introduction – A delay discounting framework for intertemporal choice.....	20
1.1 Behavioural Approaches to Intertemporal Choice.....	21
<i>1.1.1 What is delay discounting?</i>	<i>21</i>
<i>1.1.2 Theoretical Relevance of DD to Behavioural Economics</i>	<i>21</i>
<i>1.1.3 Clinical Relevance of DD</i>	<i>23</i>
<i>1.1.4 Factors which modulate the rate of delay discounting.....</i>	<i>25</i>
<i>1.1.4.1 Individual Differences.....</i>	<i>25</i>
<i>1.1.4.2 State Variables.....</i>	<i>25</i>
<i>1.1.4.3 The Sign Effect.....</i>	<i>26</i>
<i>1.1.4.4 Magnitude Effect.....</i>	<i>26</i>
<i>1.1.4.5 Domain Effect.....</i>	<i>26</i>
<i>1.1.4.6 DD Task Variables</i>	<i>27</i>
<i>1.1.5 Why is the Future Discounted?</i>	<i>27</i>
<i>1.1.5.1 A Single Process Account.....</i>	<i>27</i>
<i>1.1.5.2 Multiple process account:</i>	<i>28</i>
<i>1.1.6 Conclusions drawn from theoretical and behavioural research.....</i>	<i>29</i>
1.2 A Neural Basis of Intertemporal Choice.....	30
<i>1.2.1 Animal Literature of Impulsive choice.....</i>	<i>30</i>
<i>1.2.1.1 Neurochemistry & Neuroanatomy of Intertemporal Choice.....</i>	<i>30</i>
<i>1.2.1.2 Representing Reward Magnitude and Time.....</i>	<i>31</i>

1.2.2 Human Literature of Intertemporal Choice: ‘Neuroeconomics’	33
1.2.2.1 Characterising Neural Components of Decisions under Uncertainty.....	34
1.2.2.2 Characterising Neural Components of Intertemporal Choices: single vs. multiple valuation systems.....	35
1.2.2.3 What about Time Delays?	36
1.2.3 Conclusions from Neural Accounts of Intertemporal Choice	37
1.3 Research Aims & Objectives.....	38
CHAPTER 2: The Future is Uncertain, But only for Gains: Perceptions of Outcome Uncertainty underlie Delay Discounting	40
2.1 Abstract.....	40
2.2 Introduction	41
2.2.1 Presenting and Perceiving Uncertainty.....	42
2.2.2 Types of Uncertainty.....	44
2.3 Experiment 1: Present certainty equivalents vs. expected value	45
2.3.1 Defining discount rates for delayed and uncertain outcomes.....	45
2.3.2 Method	47
2.3.2.1 Participants	47
2.3.2.2 Discounting conditions	47
2.3.2.3 Procedure.....	48
2.3.2.4 Analysis	48
2.3.3 Results	49
2.3.3.1 Goodness of Fit.....	49
2.3.3.2 Effect of Condition.....	52
2.3.4 Discussion of Experiment 1	53
2.4 Experiment 2: Perceptions of uncertainty, magnitude and sign effects	54
2.4.1 Method	55
2.4.1.1 Participants	55
2.4.1.2 Discounting Conditions and Procedure.....	55
2.4.2 Results	55
2.4.2.1 Goodness of fit for delayed and uncertain gains & losses.....	55
2.4.2.2 Comparison between delayed and uncertain gains and losses.....	57
2.4.3 Discussion of Experiment 2	61
2.5 General Discussion	62

2.5.1 Assessment of discounting for delayed and uncertain outcomes	62
2.5.2 Implicit uncertainty underlies discounting of gains	63
2.5.3 Implicit certainty underlies attenuated discounting for losses	64
2.6 Conclusion.....	67
 CHAPTER 3: Estimating Time Intervals in the Context of Intertemporal Choices	69
3.1 Abstract.....	69
3.2 Introduction.....	70
3.2.1 Discount curves and discount rates.....	71
3.2.2 Perceived-value: discounting future utility.....	72
3.2.3 Perceived-time & time preference.....	73
3.2.4 The current study.....	74
3.3 Method	75
3.3.1 Participants.....	75
3.3.2 Procedure.....	75
3.3.3 Discounting Tasks	75
3.3.4 Consideration of Future Consequences (CFC; Strathman, et al., 1994).	76
3.3.5 Data Analysis	76
3.4 Results.....	77
3.4.1 Goodness of Fit	77
3.4.2 Task Procedure Comparisons	78
3.4 Discussion.....	80
3.5 Conclusion.....	84
 CHAPTER 4: Delay Discounting as Emotional Processing - an electrophysiological study	85
4. 1 Abstract.....	85
4.2 Introduction.....	86
4.2.1 The current study.....	89
4.3 Methods.....	90
4.3.1 Participants.....	90
4.3.2 Stimuli and Task.....	90
4.3.3 Behavioural Task.....	90

4.3.4 EEG acquisition, processing and analysis.....	94
4.4 Results	95
4.4.1 Behavioural data	95
4.4.2 Event-Related Potentials.....	96
4.4.2.1 Early detection of predictive cues	96
4.4.2.2 Early detection of feedback.....	98
4.4.2.3 Evaluation of feedback.....	99
4.5 Discussion.....	102
4.6 Conclusions	107
 CHAPTER 5: ‘If’ and ‘What’ Rewards Dissociate Risky and Impulsive Choices	108
5.1 Abstract.....	108
5.2 Introduction	109
5.2.1 Economic Parameters of Decision Making Under Uncertainty	110
5.2.2 ‘If’ as Uncertainty in Outcome Occurrence.....	111
5.2.3 ‘What’ as Uncertainty in Utility.....	111
5.2.4 The Current Study.....	113
5.3 Experiment 1: Establishing a behavioural paradigm for ‘if’ and ‘what’	113
5.3.1 Methods.....	114
5.3.1.1 Participants	114
5.3.1.2 Monetary Reward Game Stimuli	114
5.3.1.3 BIS/BAS Scale (Carver & White, 1994).....	115
5.3.1.4 Procedure	116
5.3.1.5 Practice Block	116
5.3.1.6 Monetary Reward Games.....	117
5.3.2 Results	118
5.3.2.1 Distribution of Preference.....	118
5.3.2.2 Individual differences: High vs. Low BAS	119
5.3.3 Discussion of Experiment 1	122
5.4 Experiment 2: Mapping ‘if’ and ‘what’ to ‘risky’ and impulsive’ decisions..	124
5.4.1 Methods.....	125

5.4.1.1 Participants	125
5.4.1.2 Procedure.....	125
5.4.1.3 Monetary Reward Game	126
5.4.1.4 Iowa Gambling Task (IGT: Bechara et al., 1994).....	126
5.4.1.5 Delay Discounting Task.....	126
5.4.2 Results	127
5.4.2.1 Iowa Gambling Task Results.....	127
5.4.2.2 Delay Discounting Results	128
5.4.2.3 ‘If’ and ‘What’ Results.....	129
5.4.2.3.1 Regression analysis.....	130
5.4.3 Discussion of Experiment 2	131
5.5 General Discussion	132
5.5.1 Creating variability within utility as a source of uncertainty.....	132
5.5.2 Distinguishing utility and outcome uncertainties.....	132
5.6 Conclusion.....	136
 CHAPTER 6: External Information about Potential Outcomes modifies Trait-Predicted Behavioural Preference	 137
6.1 Abstract.....	137
6.2 Introduction.....	138
6.2.1 Theoretical Framework	139
6.2.1.1 Bayesian updating based on acquired information about ‘if’.....	139
6.2.1.2 Bayesian updating based on acquired information about ‘what’	140
6.2.2. The Current Study.....	141
6.3 Method	142
6.3.1 Participants.....	142
6.3.2 Monetary Reward Game Stimuli	142
6.3.3. Personality	144
6.3.4 Procedure.....	144
6.3.5 Analysis.....	145
6.4 Results.....	146
6.4.1 Behavioural Choice	146

6.4.2 Individual Differences.....	149
6.4.3 Reaction Times	150
6.5 Discussion.....	151
6.5.1 The (in)stability of behavioural preferences: personality & context	152
6.5.1.1 Baseline preferences and personality	152
6.5.1.2 The impact of similar others in producing preference changes.....	153
6.5.1.3 Disconfirming baseline choice preferences	154
6.5.2 ‘If’ and ‘What’ as different qualities of information.....	155
6.5.2.1 Greater relevance of acquiring information about ‘what’ over ‘if’	155
6.5.2.2 Relevance of information for changes in behavioural preference	157
6.6 Summary & Conclusion	157
 CHAPTER 7: General Discussion	 159
7.1 Chapter Outline.....	159
7.2 Overview of Thesis Findings	160
7.2.1 Theme 1: Delay Discounting as Uncertainty (Chapters 2 and 3).....	160
7.2.2 Theme 2: Neural mechanisms of Intertemporal Choice (Chapter 4).....	161
7.2.3 Theme 3: Decision Making and Uncertainty as a Proxy for Intertemporal Choice (Chapters 5 and 6).....	161
7.3 Integration of thesis findings within the wider decision literature	162
7.3.1 Theme 1: Delay Discounting as Uncertainty (Chapters 2 and 3).....	162
7.3.1.1 Contributions for Delay Discounting Research	163
7.3.1.2 Methodological Contributions: Evaluation mode and attentional focus.....	163
7.3.1.3 Conceptual Contributions: cognitive and affective contributions.....	166
7.3.1.4 Limitations and Future Research	168
7.3.2 Theme 2: The Neural Basis for Intertemporal Choice (Chapter 4).....	169
7.3.2.1 Links to thesis aims:.....	169
7.3.2.1.1 Common neural signatures between decision making under uncertainty and intertemporal choice.....	169
7.3.2.1.2 Attention & Emotion	170
7.3.2.2 Links to wider neuroscience literature	171
7.3.2.3 Limitations & Future Work.....	173
7.3.3 Theme 3: Decision Making Under Uncertainty as a Proxy for Intertemporal Choice (Chapters 5 & 6).....	174

7.3.3.1 Bridging conceptual gaps: different conceptions of ‘risky’ choice.....	174
7.3.3.2 Choosing methods for risky choice.....	175
7.3.3.3 Individual differences.....	176
7.3.3.4 Limitations & Future work.....	177
7.4 Critical Assumptions: Choice as a reflection of Preference?	179
7.5 Theoretical Framework: ‘if’ ‘what’ and ‘when’ as a model of Information	
Availability	181
7.6 Conclusion.....	183
References.....	184

Word count: 59,676

List of Figures

Figure 2.1. Subjective value as a function of delay for Standard, Uncertain Outcome (Uno), and Uncertain Utility (UnU).....	51
Figure 2.2. Hyperbolic modelling using expected values and present certainty equivalents.	52
Figure 2.3. Group median subjective value as a function of delay: comparison across valence, magnitude and task condition.....	58
Figure 2.4. Mean AUC valence x task condition interaction.....	59
Figure 2.5. Mean AUC valence x task condition x amount interaction.	60
Figure 3.1. Group median estimates of reward amount and delay.....	77
Figure 4.1. Sequence of events within a single trial.....	91
Figure 4.2. Mean reaction time (ms) in response to reward and penalty cues across delay conditions.	96
Figure 4.3. Cue evoked Grand averaged ERPs.....	97
Figure 4.4. Grand averaged ERPs for early detection of feedback.	99
Figure 4.5. Grand averaged ERPs for feedback evaluation.....	101
Figure 5.1. High/Low BAS group Distribution of Forced Choice preference.....	120
Figure 5.2. Mean IGT performance across blocks of trials	128
Figure 5.3. Group median indifference points for delayed £10 as a function of time.	129
Figure 6.1. Congruency x information type interaction..	149
Figure 6.2. Mean reaction times (ms) in response to presentation of win/loss informed options	151
Figure 7.1. Outline of methodological and conceptual contributions of Chapter 2 and 3.	164
Figure 7.2. ‘Information Availability’ Framework for Decision Making under Uncertainty.	182

List of Tables

Table 2.1. Descriptive statistics for PCE values (£) observed for uncertain and delayed task conditions.	50
Table 2.2. Descriptive statistics for PCE values (£) observed for uncertain and delayed task conditions by outcome valence (gain/loss) and amount (small/large)	56
Table 3.1. Discount k and associated goodness of fit measures for hyperbolic and exponential fits to small and large rewards across task procedures.....	78
Table 3.2. Bivariate correlations between consideration of future consequences scores and delay discounting rates (AUC and k values).....	79
Table 3.3. Summary of linear regression analysis in predicting discount rate (log-transformed k values) from CFC scores.....	rolls80
Table 5.1. Choice options and associated probability/utility contingencies.....	115
Table 5.2. Spearman's correlation coefficients between BAS subscales and forced and free choice measures	121
Table 5.3. Hierarchical regression analysis: variables predicting IGT and delay discounting performance	131
Table 6.1 Choice options and associated probability/utility contingencies.....	143
Table 6.2. Mean (SD) choice option preference, proportion change in UnU option choice from baseline preference across information conditions.....	147

Abstract

Decision Making Under Uncertainty: differentiating between ‘If’, ‘What’ and ‘When’ Outcomes Occur

Marianna Blackburn, The University of Manchester

For the degree of Doctor of Philosophy (PhD)

31st January 2012

Why is it difficult to save for a pension or maintain a healthy diet? Choosing between options that have future or delayed consequences presents a challenge for a decision maker. When faced with such *intertemporal choices* the tendency to favour choices with immediate or short term outcomes, otherwise known as delay discounting, can lead to suboptimal consequences in the long-term.

However, the mechanisms underlying the devaluation of future outcomes are poorly understood. This is due to the lack of a consistent framework for the representation of delays and delayed outcomes. One perspective is to represent delays as uncertainty. However, current conceptions of uncertainty are limited, by and large, to the dimension of probability, and are therefore inadequate. This thesis adopts a delay discounting model and emphasises different types of uncertainties within choice. Unifying these components, a framework that considers intertemporal choice as decision making under uncertainty is proposed.

A series of behavioural and electrophysiological studies is presented to demonstrate that: it is the perceived uncertainty about ‘if’ and ‘when’ outcomes occur that contributes to behavioural discounting (chapters 2 and 3); the perception and evaluation of ‘what’ is delayed is underlined by emotional processes (chapter 4); and that generally, uncertainties about ‘if’ and ‘what’ outcomes differentially characterise risky and impulsive choices (chapter 5), and can be distinguished in terms of their informational qualities (chapter 6).

Collectively, these findings present a deconstruction of uncertainty into components of ‘if’, ‘what’ and ‘when’, that could be mapped to delayed outcomes. I discuss them within the context of judgement and decision making, individual differences, and neural aspects of reward processing. These results allow me to argue that 1) all decision making is a process of information availability; 2) behaviour is motivated to reduce uncertainty; 3) choice is the manifestation of acquired information gathered from a decision-maker’s internal and/or external environment.

In conclusion, this thesis demonstrates that decision making under uncertainty can be qualified beyond a single dimension of probability; and that uncertainty can be characterised as a state of incomplete information about ‘if’ ‘what’ and ‘when’ outcomes will occur. Accordingly, intertemporal and risky choices can be accommodated within a single framework, subject to the same cognitive and neural processes. Consequently, this framework allows for the design of behavioural interventions that specifically target reducing uncertainties of ‘if’, ‘what’ or ‘when’.

Declaration

No portion of work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other University or institute of learning.

All of the studies presented in this these was carried by the author. In some cases the process of data collection was undertaken in conjunction with 3rd year undergraduate Psychology students as part of their degree course research projects; Fiona Greenslade (Chapter 4), Rebecca Ward (Chapter 6).

All the work presented in this thesis was written by the author. In the cases where work has been formalised for journal publication, sections of written work have had editorial assistance from Liesbeth Zandstra and Marco Hoeksma (Chapter 4), and Wael El-Deredy (Chapters 4, 5 & 6).

Copyright Statement

- i.** The author of this thesis (including any appendices and/or schedules to this thesis) owns certain copyright or related rights in it (the “Copyright”) and s/he has given The University of Manchester certain rights to use such Copyright, including for administrative purposes.
- ii.** Copies of this thesis, either in full or in extracts and whether in hard or electronic copy, may be made only in accordance with the Copyright, Designs and Patents Act 1988 (as amended) and regulations issued under it or, where appropriate, in accordance with licensing agreements which the University has from time to time. This page must form part of any such copies made.
- iii.** The ownership of certain Copyright, patents, designs, trademarks and other intellectual property (the “Intellectual Property”) and any reproductions of copyright works in the thesis, for example graphs and tables (“Reproductions”), which may be described in this thesis, may not be owned by the author and may be owned by third parties. Such Intellectual Property and Reproductions cannot and must not be made available for use without the prior written permission of the owner(s) of the relevant Intellectual Property and/or Reproductions.
- iv.** Further information on the conditions under which disclosure, publication and commercialisation of this thesis, the Copyright and any Intellectual Property and/or Reproductions described in it may take place is available in the University IP Policy (see <http://www.campus.manchester.ac.uk/medialibrary/policies/intellectual-property.pdf>), in any relevant Thesis restriction declarations deposited in the University Library, The University Library’s regulations (see <http://www.manchester.ac.uk/library/aboutus/regulations>) and in The University’s policy on presentation of Theses.

Acknowledgements

Firstly, I would like to thank Wael El-Deredy, who has been both my supervisor and human ‘white board’ for all the thoughts, hypotheses and questions that I have had throughout this journey. I am incredibly grateful for the opportunity he gave me to undertake this project four years ago, and for the fact that in all that time, he has never stopped believing it would all come together...even when I did.

I would also like to thank my team of advisors; Rebecca Elliot, in the Faculty of Life Sciences, for her thoughtful and always calming reassurance; Luke Jones, who, whilst not official, through his efforts and advice, has proved worthy of honorary advisor status; additionally, Liesbeth Zandstra and Marco Hoeksma, at Unilever R&D Vlaardingen, who have been an invaluable link to the world of research within industry, and have constantly reminded me why this thesis is important.

I am also grateful to Garry Byrne and Yu Li, part of the wonderful IT team within the School of Psychological Sciences, their assistance in all matters of computing, as well as my psychology undergraduate students over the years, all of whom have been instrumental in the collection of data for this thesis.

I am also immensely thankful to Sarah Davies, Laura Mirams, Alexis Makin, Sandra Ortega-Martorell, and Caroline Lea-Carnall, with whom I have had the pleasure of sharing an office with over the last four years; their patience and encouragement through all the good and not so good times has gone beyond the mere call of colleagues, and I am honoured that I can count them as close friends.

Last, but by no means least, I would like to thank my parents, who have given their encouragement, love, support and anything else they could have provided, without question or hesitation. I am indebted to the loving home they have provided me with as a sanctuary for completing this thesis; the many nights they have patiently listened as I have pieced this work together, often with many tears; and their unfailing belief that I would get there in the end. I could not have done this without you. Thank you.

List of Abbreviations

AUC	Area Under the Curve
BAS	Behavioural Activation System
CDM	Clinically-Related Decision Making
CFC	Consideration of Future Consequences
DA	Dopamine
DD	Delay Discounting
DD-A	Adjust Amount Delay Discounting Task
DD-T	Adjust-Time Delay Discounting Task
DLPFC	Dorsolateral Prefrontal Cortex
EEG	Electroencephalography
EPN	Early Posterior Negativity
ERP	Event Related Potential
EV	Expected Value
FITB	Fill in the Blank Discounting Task
fMRI	Functional Magnetic Resonance Imaging
fRN	Feedback Related Negativity
IGT	Iowa Gambling Task
ITC	Intertemporal Choice
JDM	Judgement and Decision Making
OFC	Orbitofrontal Cortex
PCE	Present Certainty Equivalent
RT	Reaction Time
UnO	Uncertainty in Outcome Occurrence/likelihood
UnU	Uncertainty in Outcome Utility

The Author

Marianna Blackburn completed her Undergraduate degree in Neuroscience with Industrial Placement at the University of Manchester in 2005, spending the one-year industrial placement at Unilever Research & Development at Port Sunlight, UK. She completed a Master's degree in The History of Science & Medicine at the University of Manchester in 2007. Her PhD research was supported by a Biotechnology and Biological Sciences Research Council (BBSRC) CASE-Award.

Publications and Conference Presentations

Parts of this thesis appear in other publications by Marianna Blackburn and colleagues:

Based on Chapter 2:

Blackburn, M., & El-Deredy, W. The Future is Uncertain, but only for gains: perceptions of outcome uncertainty underlie delay discounting. *Currently being revised for publication in Behavioural Processes.*

Based on Chapters 3

Blackburn, M., Jones, L., & El-Deredy, W. Estimating Time Intervals in the Context of Intertemporal Choice. *Currently under review at the Journal of Experimental Analysis of Behaviour.*

Based on Chapters 4

Blackburn, M., Mason, L., Hoeksma, M., Zandstra, L & El-Deredy, W. Delay Discounting as Emotional Processing: an electrophysiological study. *Cognition & Emotion (in press).*

Mason, L., O'Sullivan, N., Blackburn, M., Bentall, R., & El-Deredy, W. (2012). I Want it Now! Neural Correlates of Hypersensitivity to Immediate Reward in Hypomania. *Biological Psychiatry*, 71(6), 530-537.

The research reported in this thesis has also led to the following conference presentations:

11th International Conference on Cognitive Neuroscience (ICON XI), *Mallorca, Spain, September 2011*. Poster presentation: It's worse than you thought: the feedback negativity and response to delayed rewards.

16th Annual Meeting of the Organisation for Human Brain Mapping, *Barcelona, Spain, 2010*. Poster presentation: Delay Discounting as Emotion: an ERP study.

17th Annual Meeting for the Cognitive Neuroscience Society, *Montreal, Canada, April 2010*. Poster presentation: The Differential effects of risk and ambiguity in evaluating delayed rewards.

10th International Conference on Cognitive Neuroscience (ICON X), *Bodrum, Turkey September 2008*. Poster presentation: What's so Uncertain about Uncertainty? Decision making under different uncertainties.

Thesis Background: the bigger picture

Incentives are often provided to motivate desired behaviour change, i.e. contingency management (e.g. Peirce, et al., 2006) and have proved successful in effecting behaviour change within substance abuse domains (Higgins, Alessi, & Dantona, 2002; Petry, Alessi, & Hanson, 2007). More recently, the use of contingency management to motivate and sustain weight loss within overweight and obese populations has received increasing focus. However, whilst incentives prove a significant motivator for weight loss (Finkelstein, Linnan, Tate, & Birken, 2007; Jeffery, Gerber, Rosenthal, & Lindquist, 1983; Kane, Johnson, Town, & Butler, 2004), their efficacy does not translate to long term behaviour change (Kane, et al., 2004).

It has been suggested that in order to effect successful behaviour change, incentives should be directed towards the motivation and reinforcement of behaviours which can be sustained over time; therefore, not weight loss *per se*, rather, behavioural choices which are conducive to a healthy lifestyle, for example making healthy food choices and the undertaking of physical activity (Paul-Ebhohimhen & Avenell, 2008).

However, when making healthy choices, the benefits of which lie in the future, must compete with those which satisfy immediate gratification. Such *intertemporal choices* present a challenge for a decision maker, and there is a tendency to favour immediate gratification over rewards which are delayed in the future. This preference is suggested to be driven by a reduction in value of delayed outcomes, a phenomenon referred to as temporal (delay) discounting.

Understanding the mechanisms which underlie delay discounting and the subsequent impact on decision making is critical to understanding how competing incentives may function to promote long term goals. This thesis contributes a theoretical understanding of the psychological and neural mechanisms that underlies delay discounting within the context of decision making with delayed and uncertain consequences.

CHAPTER 1: General Introduction – A delay discounting framework for intertemporal choice

Many of the choices we face involve a trade-off between immediate and delayed benefits. For example, adopting and maintaining a healthy lifestyle and saving for a pension require forgoing immediate rewards in favour of more optimal yet delayed benefits. Such *intertemporal choices* prove challenging, as one can never guarantee with certainty *when* outcomes will occur, *if* they will occur and *what* they will consist of. In other words, the future invites a number of uncertainties. It is therefore not surprising that people tend to favour choices with immediate outcomes rather than wait for more optimal yet delayed consequences.

Despite a long tradition within both economic and clinically related fields of research, a single framework that embodies considerations of time and uncertainties has remained elusive. Instead, the study of decisions involving delayed and uncertain outcomes have largely progressed along two distinct trajectories, and their attempts to coincide have not proved consistent or conclusive.

In this chapter, I will review the predominant theoretical and experimental framework that has been used to address intertemporal choice; *delay discounting*. By reviewing the key findings within behavioural and neuroscience literatures, I shall highlight potential convergence points that have been made with decisions under uncertainty. By considering these aspects, both intertemporal choices and decision making under uncertainty may be viewed as a reflection of a common decision network which is revisited at length in the general discussion (Chapter 7).

1.1 Behavioural Approaches to Intertemporal Choice

1.1.1 What is delay discounting?

Within intertemporal choices, the behavioural tendency to prefer immediate over temporally distant rewards is often considered as exemplar of ‘impulsive choice’ (Ainslie, 1975). Impulsive choice reflects one of many behavioural dimensions of ‘impulsiveness’ (Evenden, 1999) and is considered to underlie a number of sub-optimal behaviours, for example, binge drinking, and an overreliance on credit cards (see Reynolds, 2006). Such impulsive tendencies can be accounted for by delay discounting (DD), which refers to the subjective devaluation of outcome value as a function of delay.

Determining the degree to which individuals discount the future can be achieved through the use of psychophysical-type choices between a small immediate small and larger delayed reward (Rachlin, Raineri, & Cross, 1991). Individuals are asked to select which option they would (hypothetically) prefer, and incremental adjustments are made (usually made to the immediate reward) until there is a reversal in preference or the individual is indifferent between the two options. Across a number of delays, indifference points for each delay can be plotted to reveal a subjective value curve, from which a discount function can be computed (see Chapters 2 & 3). Individuals who prefer smaller sooner rewards tend to report lower value indifference points, which result in steeper discount curves, and are considered more impulsive. Conversely, selecting larger delayed rewards results in higher value indifference points and shallower discounting, reflecting greater self-control.

1.1.2 Theoretical Relevance of DD to Behavioural Economics

Discounted Utility Theory (DUT; Samuelson, 1937) provides a normative framework to account for intertemporal choice. A critical feature of this model is that subjective value declines according to an exponential function (Eq.1), implying a given time delay will have the same impact on value and preference, regardless of when it occurs (for review see Loewenstein & Prelec, 1992)

$$V = Ae^{-kD} \quad \text{Equation 1}$$

Where V represents the subjective value of the future reward, A the amount of expected reward, D the time delay to its receipt, and k is the individually different parameter governing the rate of devaluation.

Exponential decay functions are derived from the assumption that with each additional unit of time, there is a constant probability (i.e. hazard rate) that some event may intervene to prevent an outcome's receipt (Green & Myerson, 1996; Kagel, Green & Caraco, 1986; Sozou, 1998). In this way, larger values of k implies a greater risk (i.e. the probability that reward receipt will be prevented), or a greater sensitivity to risk.

However, behavioural evidence has consistently shown that rewards delivered with shorter delays are discounted more steeply than those delivered with longer delays, and are best described according to a hyperbolic model (Equation 2) (Mazur, 1987):

$$V = A/(1 + kD) \quad \text{Equation 2}$$

Where V , A and D carry the same meaning as Eq. 1

Whilst a more appropriate description of observable data, the application of Mazur's model in human studies shows a tendency to over-predict subjective values at more proximal time delays, and under-predict subjective values at more distal time delays (Green & Myerson, 2004). To provide more closer approximations, several mathematical variants of the hyperbolic form have been presented which take to account individual differences in the scaling of amount and/or time (e.g. Myerson & Green, 1995; Rachlin, 2006), the multiplicative combination of discount parameters for reward magnitude, delay and odds-against occurrence (e.g. Ho, Mobini, Chiang, Bradshaw & Szabadi, 1999), and logarithmic time perception (i.e. Weber-Fechner law; Takahashi, Oono, & Radford, 2008). The development of such variants to a single parameter model reflects one dimension of delay discounting research for which the agenda lies in

determining the form of discounting function that best describes data. This agenda is relevant as different mathematical equations imply different underlying assumptions concerning the decision process (Green & Myerson, 2004). However, assessing which model provides a more appropriate description of data is often made on the basis of the proportion of variance accounted for. Variant models which include additional parameters (e.g. Myerson & Green, 1995; Rachlin, 2006) will invariably provide a better approximation of data, relative to the single parameter model. However, whilst comparisons across variant models are limited, there is evidence to suggest such alternative models provide equally desirable fits to data (McKerchar, Green, Myerson et al., 2009). In this respect, dimensions of DD research which focus less on the form of discounting, and more on the ways in which discounting may be modulated by both internal and external factors have tended to rely on a simpler hyperbolic model (Eq. 2), and remains the most widely utilised description for delay discounting in studies of behavioural neuroeconomics and psychopharmacology (see Kalenscher & Pennartz, 2008). As such, the single parameter model will provide the basis for the work conducted in this thesis.

The primary significance of a hyperbolic model lies in its ability to account for time inconsistencies; that is, where individuals reverse their preferences when immediate and delayed rewards are advanced by the same time interval (Green, Myerson, & Fristoe, 1994). At the same time however, a hyperbolic account directly challenges the assumption that implied risks underlie the future discounting. Nevertheless, given that preferences reversals are poorly understood the issue of time inconsistency and violations to rational accounts of discounting remains contentious within economic circles (see Kalenscher & Pennartz, 2008; Read, Frederick, Orsel, & Rahman, 2005; Read & Roelofsma, 2003). As such, the view that delayed outcomes are uncertain has not been ruled out (e.g. Weber & Chapman, 2005).

1.1.3 Clinical Relevance of DD

Understanding the mechanisms which underlie DD is not only a theoretical matter, but also appeals to clinical research domains. ‘Impulsiveness’ is a defining taxonomy within psychiatric classifications (e.g. DSM-IV; American Psychiatric Association, 1994).

Whilst this term is a general one applied to a group of disorders which exhibit a failure to resist an impulse, drive or temptation as core feature, it is acknowledged that the term impulsiveness encompasses a variety of related phenomena, such as response inhibition, impaired temporal differentiation, and preference for smaller sooner rewards over those which are larger yet delayed, or ‘impulsive choice’ (see Evenden, 1999; Ho, et al., 1999). As such, whilst studies of DD are relevant for understanding the potential mechanisms which contribute towards impulsive choice, it is unlikely, or at least unclear as to how they aid interpretations of alternative variants of ‘impulsiveness’ (Evenden, 1999).

Nevertheless, a greater tendency to prefer immediacy, and thus discount the future more steeply characterizes a number of addictive behaviors such as cigarette smoking (Baker, Johnson, & Bickel, 2003; Mitchell, 1999; Ohmura, Takahashi, & Kitamura, 2005; Reynolds, Richards, Horn, & Karraker, 2004), opioid (Giordano, et al., 2002; Kirby, Petry, & Bickel, 1999; Madden, Petry, Badger, & Bickel, 1997; Odum, Madden, Badger, & Bickel, 2000) and cocaine use (Coffey, Gudleski, Saladin, & Brady, 2003; Heil, Johnson, Higgins, & Bickel, 2006), problem drinking (Petry, 2001; Vuchinich & Simpson, 1998), pathological gambling (Dixon, Marley, & Jacobs, 2003; Reynolds, 2006) and obesity (Weller, Cook, Avsar, & Cox, 2008). However, it is unclear whether an inherently higher discounting rate precludes addictive processes, or whether addiction fosters the development of higher discounting, although, like most ‘state vs. trait’ accounts, both perspectives are viewed as contributing factors.

For instance, substance users consistently demonstrate steeper discounting for a delayed drug of choice over an equivalent monetary value (Bickel, Odum, & Madden, 1999; Coffey, et al., 2003; Odum, et al., 2000; Petry, 2001). However, both opioid users (Giordano, et al., 2002) and smokers (Field, Santarcangelo, Sumnall, Goudie, & Cole, 2006; Mitchell, 2004) show steeper DD when drug deprived relative to satiated states.

1.1.4 Factors which Modulate the Rate of Delay Discounting

DD rates also vary within the general population as a function of demographic variables such as age, income and education (e.g. Green, Myerson, Lichtman, Rosen, & Fry, 1996; Kirby, Winston, & Santiesteban, 2005). However, understanding the factors which influence impulsive choice as demonstrated by measured DD rates has largely focused on factors of individual differences and contextual variables.

1.1.4.1 Individual Differences

Both cognitive abilities and personality variables have been documented as individual difference factors associated with DD rates. For instance, it has been consistently shown that individuals with higher intelligence demonstrate significantly lower rates of DD (de Wit, Flory, Acheson, McCloskey, & Manuck, 2007; Shamosh & Gray, 2008). Similarly, relationships between steeper DD as a function of working memory load (e.g. Hinson, Jameson, & Whitney, 2003) have implicated cognitive abilities which support the active maintenance of goal-relevant information.

Less consistent however are findings concerning personality trait influences on DD. For instance, whilst several studies have shown positive relationships between DD and self-report measures of impulsivity (Wit, et al., 2007; Mobini, Grant, Kass, & Yeomans, 2007; Swann, Bjork, Moeller, & Dougherty, 2002), others have failed to find such associations (Lane, Cherek, Pietras, & Tcheremissine, 2003; Mitchell, 1999; Brady Reynolds, Ortengren, Richards, & de Wit, 2006).

1.1.4.2 State variables

Considering a state variable as one which influences behavior over a relatively short time frame, factors such as outcome magnitude, sign and domain have been consistently shown to modulate discount rates. Although these factors can be considered in a similar manner to the framing effects reported for decisions under risk (c.f. Loewenstein & Prelec, 1992), an explanatory account for magnitude, sign and domain effects observed in DD studies is still warranted.

1.1.4.3 The Sign Effect

Although the majority of discounting research has focused on the subjective devaluation of gain outcomes, a small number of studies have explored whether negative outcomes are evaluated in the same way. The general consensus is of a gain/loss asymmetry, with steeper discounting for delayed gains compared to losses and is commonly referred to as the sign effect (Green & Myerson, 2004). Such asymmetry suggests delay discounting is more likely driven by a preference for immediacy, rather than aversion to delays per se; however, it is widely acknowledged that gains and losses are differentially processed in term of neural mechanisms, and therefore could possibly be subject to different discounting processes.

1.1.4.4 Magnitude Effect

A more widely documented observation is the magnitude effect, referring to the steeper discounting of smaller relative to large delayed rewards (Green, Myerson, & McFadden, 1997; Kirby & Marakovic, 1996; Myerson & Green, 1995; Raineri & Rachlin, 1993). The greater focus on magnitude effects is partly reflective of the asymmetrical impact of magnitude on delay and probabilistic discounting (section 1.1.5.1).

1.1.4.5 Domain Effect

As previously described in the case of addiction, discount rates were highly dependent on whether the commodity was the drug of choice, or hypothetical money. This modulation of discount rates as a function of commodity, or domain effect, has been documented for a range of commodities such as delayed health gains (Chapman, 1996; Chapman & Elstein, 1995), vacations (Raineri & Rachlin, 1993), alcohol (Odum & Rainaud, 2003), food (Estle, Green, Myerson, & Holt, 2007; Odum & Baumann, 2007; Odum, Baumann, & Rimington, 2006) and various media (Charlton & Fantino, 2008). Generally, consumable rewards such as food and beverages, tend to be discounted more steeply than entertainment media, and money, reflecting a continuum anchored according to metabolic function (Charlton & Fantino, 2008).

1.1.4.6 DD Task Variables

In addition to DD modulation as a function of choice attributes (e.g. reward magnitude) features of the DD task also influence behavioural choice preferences. Procedural variants such as experienced consequential choice (Lane, et al., 2003; Reynolds, Richards, & de Wit, 2006), order of immediate reward presentation (Robles & Vargas, 2007), choice evaluation mode (Smith & Hantula, 2008) and attribute framing (Read, et al., 2005) produce shifts in the degree of discounting, whilst maintaining consistency with a hyperbolic model.

1.1.5 Why is the Future Discounted?

Whilst both state and trait factors contribute towards behavioural preferences for immediate and delayed outcomes, such findings do not address why DD arises to begin with. Two main positions are held on this issue: a single process view in which discounting arises as a function of a single valuation mechanism, and can be accounted for by uncertainty. Alternatively, a dual-process view which focuses on the interaction between two separate and competing decision processes.

1.1.5.1 A Single Process Account

In a similar manner to the way in which subjective value is sensitive to increasing time delays, subjective value is also influenced by decreasing probabilities. For instance, small rewards that are certain are preferred over larger rewards that probabilistic. Such behavioural preferences can be collected in an analogous manner to DD tasks, and produce discounting that also follows a hyperbolic form (Equation 3) (Rachlin, et al., 1991):

$$V = A/(1 + h\theta) \quad \text{Equation 3}$$

Where V represents the subjective value of a probabilistic reward of amount A , h is a parameter analogous to k in Eq. 1, and θ represents the odds against the receipt of reward ($\theta = 1-p / p$, p being probability of reward)

The mathematical similarity between delay and probabilistic discounting (PD) makes a single discount mechanism an intuitive possibility, and is appealing from the perspective of a ‘common currency’ (Montague & Berns, 2002). However, behavioural evidence has not fully supported such a view. Using the psychophysical-type mode of assessment, comparisons between discounting rates from DD and PD tasks have proved inconsistent, and are limited by assuming increasing delays as equivalent to decreasing probabilities; similarly, a consistent observation is that delay and probabilistic discounting are affected by magnitude in opposing directions (Du, Green, & Myerson, 2002; Green, Myerson, & O’Donoghue, 1999; Myerson, Green, Scott Hanson, Holt, & Estle, 2003). Greater support for a single process view stems from investigations based on alternative methodologies that reconsider these two parameters within a single paradigm, e.g. combining immediacy and certainty effect biases, self-reported uncertainty (Pataki & Reynolds, 2007; Reynolds, Pataki, & Shroff, 2007; Weber & Chapman, 2005; See Chapter 2).

1.1.5.2 Multiple process account:

An alternative perspective is that hyperbolic discounting arises from the interaction between two decision processes that have competing goals. This view draws heavily on previous descriptions of self-control, which delineate between ‘hot’ and ‘cool’ states (Metcalf & Mischel, 1999). For instance, a ‘hot’ emotional system with a myopic present-orientated ‘self’ dealing with short term goals, competes with a ‘cool’ reasoning system that aligns with a far-sighted ‘self’ and considers the costs and benefits associated with future planning (Bechara, 2005; Laibson, 1997). The advantage of such a perspective is the incorporation of alternative dimensions that are relevant for ITC, such as affective and anticipatory influences, the notion of representation and of course, self-control (Berns, Laibson, & Loewenstein, 2007; Trope & Liberman, 2003). These are dimensions which a DD framework has so far not addressed, but which have been acknowledged in relation to decisions making under uncertainty (e.g. Finucane, Alhakami, Slovic, & Johnson, 2000; Mellers & Schwartz, 1997).

Whilst a plausible account for explaining the steeper discounting of more proximal rewards relative to the shallow discounting of remote rewards that characterise hyperbolic discounting, behavioural experimental evidence within a DD framework is lacking. The majority of evidence favouring a dual-systems account has come from neural approaches of ITC (see section 1.2.2.2).

Furthermore, a dual-systems view of hyperbolic discounting, by its virtue, dismisses the possibility that decisions over time and under uncertainty are comparable.

1.1.6 Conclusions drawn from theoretical and behavioural research

Whilst there is a substantial literature concerning the factors which contribute to whether a decision favours immediate over delayed outcomes, there remains a lack of clarity over the underlying mechanisms which give rise to DD. Although an intuitive consideration is that the future is uncertain, previous studies have only addressed whether choices for delayed and probabilistic outcomes coincide via a single discount mechanism, the findings of which have been inconclusive. The view that delayed outcomes are discounted because they are *perceived* as uncertain has not been addressed (Chapter 2).

By focusing predominantly on the hyperbolic nature of discounting, alternative dimensions such as outcome anticipation, representation and self-control which are also known to impact subjective valuation, have been neglected. Similarly, contrary to the increasing appreciating of affective processes within decision making under uncertainty, the role of emotions have not been considered within a DD framework, despite their relevance to dual-process accounts of self-control (Chapter 4).

1.2 A Neural Basis of Intertemporal Choice

Understanding the neural mechanisms that underlie delay discounting and thus support intertemporal choices have been approached in a number of ways. For example, animal studies have identified specific neuronal networks that support the representation of time and amount variables, and their integration (for review see Kalenscher & Pennartz, 2008). In humans, functional neuroimaging studies (fMRI) have followed a neuroeconomic approach, and focused primarily on the debate between single vs. multiple systems.

1.2.1 Animal Literature of Impulsive choice

1.2.1.1 Neurochemistry & Neuroanatomy of Intertemporal Choice

Both animal lesion studies and pharmacological manipulations have indicated neural regions and neurotransmitter systems that support intertemporal choices. Two prime candidates revealed by pharmacological manipulations (although, not exclusively) are serotonergic (5HT) and dopaminergic (DA) systems. Serotonin is particularly associated with impulse control, as drugs which suppress 5HT function result in reduced behavioural inhibition, i.e. animals display ‘motor’ impulsivity (Evenden & Ryan, 1999). However, 5HT depletion studies in both animal and human studies have produced inconsistent and conflicting findings concerning the effect on discounting (Kalenscher, Ohmann, & Gunturkun, 2006), providing support for the multifactorial view of ‘impulsivity’.

Like serotonergic manipulations, drugs which alter dopaminergic functioning can also increase or decrease impulsive choice, for example, amphetamine and similar psychostimulants (Elia, Ambrosini, & Rapoport, 1999). The efficacy of psychostimulants is hypothesised to act through promoting choice of delayed rewards (de Wit, Enggasser, & Richards, 2002; Mobini, Chiang, Al-Ruwaitea, Ho, Bradshaw, & Szabadi, 2000; Solanto, 1998; Wade, de Wit, & Richards, 2000). Conversely, antagonists which act at D₂ but not D₁ dopamine receptors decrease the value of delayed rewards, i.e. increase impulsive choice (Wade, et al., 2000), suggesting a role of dopamine in delayed reinforcement and hence choice may be implicated at a receptor level. Given that dopamine D₂ receptor levels are strongly implicated in addiction and

obesity (Volkow, et al., 2008; Wang, Volkow, Thanos, & Fowler, 2004; Yasuno, Suhara, & Sudo, 2001), dopaminergic functioning provides a potential common mechanism to describe similarities in impulsive choice observed.

In terms of neuronal structures involved in ITC, animal lesion studies have shown preferences for smaller immediate rewards, i.e. impulsive choice, can be induced by lesions to the nucleus accumbens core, basolateral amygdala, the orbitofrontal cortex, hippocampus and striatum, whereas self-control, a preference for delayed options can be induced by lesions to the orbitofrontal cortex and sub-thalamic nucleus (Winstanley, Theobald, Cardinal, & Robbins, 2004). Although such approaches cannot determine whether impulsive choice arises from changes in delay discounting or changes in reward magnitude sensitivity, they have indicated different neural structures may play differential roles in impulsive choice behaviour.

1.2.1.2 Representing Reward Magnitude and Time

Animal paradigms allow for intracranial recording of electrical activity in distinct neural structures during the presentation of reward predicting cues, or during the delay between cue and reward outcome, and allows for a more precise investigation of decision variables, i.e. reward magnitude and delays both as independent constituents and as an integrative signal of expected reward amount.

For example, neuronal activity within the dorsolateral prefrontal cortex (DLPFC) (Leon & Shadlen, 1999; Wallis & Miller, 2003) and the orbitofrontal cortex (OFC) (Roesch & Olson, 2004; Schoenbaum, Chiba, & Gallagher, 1998; van Duuren, et al., 2007) is modulated by the magnitude of expected reward in response to a reward-predicting cue, or during the delay between cue and reward delivery. Such findings suggest that frontal structures are involved in representing and maintaining the value of expected rewards. Furthermore, activity within the OFC (Roesch, Taylor, & Schoenbaum, 2006), DLPFC (Watanabe, 1996), basolateral amygdala (Baxter & Murray, 2002), the nucleus accumbens (Hassani, Cromwell, & Schultz, 2001) discriminates between both the quantity and quality of expected rewards.

A distributed set of regions are also sensitive to features of anticipated and elapsed delays. For instance, time-dependent ramping activity has been shown in areas of the posterior parietal cortex (Leon & Shadlen, 2003) the ventral striatum (Izawa, Aoki, & Matsushima, 2005), and frontal cortical regions including the PFC, pre-motor cortex, frontal and supplementary eye field (Roesch & Olson, 2005).

Although informative of the type and location of neural activity during anticipatory periods, these findings utilise relatively short delays (within the seconds range). As such, it is not clear whether neural activity reflects time delays *per se*, and whether such patterns of neural activity are applicable to the long term delays that are unique to human intertemporal choice.

In terms of integrating parameters of reward amount and time to represent a combined discounted value, the majority of studies (within animals) have focused on the OFC, given neuronal activity within this brain region reflects the value of anticipated reward (Critchley & Rolls, 1996; Roesch & Olson, 2004), the delivery or absence of reward (Tremblay & Schultz, 2000), large or small rewards (Roesch & Olson, 2004; Wallis & Miller, 2003), preferred and non-preferred rewards (Hikosaka & Watanabe, 2000, 2004) and changing reward value under reinforcement devaluation tasks (Baxter & Murray, 2002; Baxter, Parker, Lindner, Izquierdo, & Murray, 2000; Pickens, et al., 2003). Collectively, these findings suggest the OFC plays a critical role within a valuation circuit that is capable of evaluating disparate types of future reward; in other words, the OFC may provide the platform for a ‘common currency’ (Montague & Berns, 2002).

A second candidate for implementing a common currency are dopaminergic midbrain structures (Izawa, et al., 2005; Roesch, Calu, & Schoenbaum, 2007; Tobler, Fiorillo, & Schultz, 2005). Dopamine (DA) neurons have been consistently found to play an intricate role in reward processing in both humans and animals (Berridge & Robinson, 1998; Schultz, 1997; Schultz, 2001; Wise & Bozarth, 1981; Wise & Rompre, 1989) and are responsive to both rewards and reward predicting stimuli (Fiorillo, Tobler, & Schultz, 2003; Roitman, Stuber, Phillips, Wightman, & Carelli, 2004; Schultz, 1998; Waelti, Dickinson, & Schultz, 2001) as well the absence of rewards when they are omitted (Tobler, Dickinson, & Schultz, 2003). Specifically, dopamine neurons have

been shown to integrate parameters of magnitude and probability (Tobler, et al., 2005) signalling overall expected value, in a manner that corresponds with a temporal difference (TD) prediction error δ (McClure, Daw, & Montague, 2003; Schultz, 1998; Schultz, 2001; Schultz, Dayan, & Montague, 1997; Schultz, Tremblay, & Hollerman, 1998), i.e. the difference between predicted and actual reward.

Although less well established, dopamine neurons would appear to also encode future reward predictions on the basis of delay in a similar manner. For example, dopamine neurones can encode prediction errors in response to unexpected changes in reward value arising from either delay or magnitude, and thus reflect the subjective value of delayed rewards (Roesch, et al., 2007). In a related study, neural activity in response to cues predicting the proximity and magnitude of food reward revealed specific representation of these two parameters within the ventral striatum (Izawa, et al., 2005). The implications of these findings are that firstly, dopaminergic structures encode parameters of delay and magnitude, both independently, and as a combined value signal. Secondly, they draw a parallel with between delay and uncertainty coding in the form of prediction errors.

1.2.2 Human Literature of Intertemporal Choice: 'Neuroeconomics'

Investigating the neural correlates of human intertemporal choice has been approached largely under the rubric of 'neuroeconomics' (Loewenstein, Rick, & Cohen, 2008). A neuroeconomic approach reflects the integration of formal theories of decision making from economics with neuroscientific methods to investigate how the brain computes reward value. A central agenda lies in elucidating a common currency (Montague & Berns, 2002; Montague & King-Casas, 2007), and therefore holds potential for uniting decisions involving uncertainty and delay.

1.2.2.1 Characterising Neural Components of Decisions under Uncertainty

From a normative standpoint, both the expectation of reward magnitude and probability give rise to the concept of subjective expected utility (Savage, 1954; von Neumann & Morgenstern, 1944). Expected Utility represents the option with the highest value, and can act as a common ‘currency’ for comparisons between options (Sanfey, 2007; Sanfey, Loewenstein, McClure, & Cohen, 2006); In this way, decisions are driven by the aim of maximising utility.

Utilising this framework, fMRI studies have systematically revealed both brain regions and neurons¹ that are capable of encoding parameters of reward magnitude (Delgado, Locke, Stenger, & Fiez, 2003; Elliott, Newman, Longe, & Deakin, 2003; Knutson, Adams, Fong, & Hommer, 2001) and uncertainty, predominantly as probability (Fiorillo, et al., 2003; Yang & Shadlen, 2007), both as functionally distinct components (Yacubian, et al., 2007) and combined as expected value (Tobler, O'Doherty, Dolan, & Schultz, 2007). Thus, the brain can encode reward as a constructed entity, yet still remain sensitive to aspects of variations in reward magnitude, probability (for review see Fellows, 2004; Glimcher & Rustichini, 2004; Lee, 2005; Trepel, Fox, & Poldrack, 2005).

However, the goal of neuroeconomics is more than just mapping mathematically based theories of choice to neural functioning; this approach seeks to address how cognitive and emotional factors affect choice, and explain violations to rational theory.

For example, people are sensitive to whether probabilities are known, and whether outcomes are framed as gains or losses, which run counter to a normative view. Such violations can be attributed to emotional processing; for instance, risky decisions recruit amygdala and OFC regions (e.g. Vorhold, et al., 2007) which are implicated in processing and integrating emotional and cognitive inputs (Critchley, Mathias, & Dolan, 2001). However, greater engagement of these regions is observed in response to choices

¹ These regions are similar to those identified in animal studies, e.g. OFC, striatum and dopamine neurons, or their human analogues.

offering unknown chances of winning, i.e. ambiguous, compared to alternatives presented with defined probabilities, e.g. a 50% chance of winning (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005). Similarly, the engagement of amygdala and insula regions is observed in response to potential losses, accounting for loss aversion under risk (De Martino, Kumaran, Seymour, & Dolan, 2006; Kuhnen & Knutson, 2005)

1.2.2.2 Characterising neural components of intertemporal choices: single vs. multiple valuation systems

However, applying a framework that parses neural activity in response to parameters of reward magnitude and delay both as independent components and combined as delayed subjective value has not fully been addressed for ITC. Rather, neuroeconomic approaches towards ITC have addressed the single vs. multiple systems debate, and have focused primarily on relationships between neural activity and behavioural models of discounting (e.g. exponential, hyperbolic or quasi-hyperbolic).

For instance, modelling brain activity according to Laibson's (1997) quasi-hyperbolic (β - δ) model, and using monetary gift certificates, McClure et al., (2004) distinguished between two neural systems; a myopic impatient system (β) which showed preferential recruitment of limbic regions including the ventral striatum, OFC and mOFC when immediate rewards were present, and a patient far-sighted system (δ) that was activated by all choices, comprising the lateral PFC and posterior parietal cortex (PPC). These findings were replicated in a follow up study, exchanging secondary rewards for primary rewards of juice and water, and reducing the time scale employed (from day of testing – 6 weeks, to 0s – 25 minutes). Despite the longest duration (i.e. 25 minutes) being sooner than the earliest delay in their previous study, these delayed rewards did not activate the β -system. The authors hypothesised that β -system activation may reflect the relative value of delays. However, shifting of all delays by 10 minutes, so that the earliest reward was delivered at $t = 10$ minutes, did not confirm this assumption. Rather, participants treated immediate rewards delivered after 10 minutes as delayed, suggesting the β -system responds to absolute delays.

Conversely, support for a single valuation system has been derived from fMRI studies using a single hyperbolic model. For example, Hariri, and colleagues observed ventral striatal activity positively correlated with individual delay discounting k parameter², such that participants displaying greater percentage BOLD signal changes in response to positive or negative monetary rewards, also displayed steeper, thus more impulsive, discounting (Hariri, Brown, Williamson, et al., 2006). Relating neural activity to subjective value directly, Kable & Glimcher (2007) reported activity within the ventral striatum, mOFC and posterior cingulate cortex tracked the subjective value irrespective of delay, implying neural activity reflects the saliency of reward outcomes (see Chapter 4).

1.2.2.3 What about Time Delays?

Unlike animal approaches, human studies have not addressed whether or how parameters of delay are represented in the context of intertemporal choice. Neural accounts of interval timing reveal a distributed network including the striatum, cerebellum, thalamus and prefrontal cortex, are involved in processing different components of time perception, such as attending to time, encoding intervals and representing time durations (for a review see Buhusi & Meck, 2005; Ivry & Spencer, 2004; Wittmann & Paulus, 2008). This distributed network overlaps in places with regions involved in the processing reward value (e.g. striatum), potentially supporting a view of a single valuation mechanism that incorporates reward amount and time. Similarly, states and conditions in which impulsive choice is a core feature as defined by steeper discounting, are also related to altered time perception (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Reynolds & Schiffbauer, 2004; van den Broek, Bradshaw, & Szabadi, 1992; Wittmann, Leland, Churan, & Paulus, 2007). However, studies which investigate interval timing have only employed delays within the seconds range, and thus choices involving time delays which span days, months and years may recruit entirely different neural mechanisms (Lewis & Miall, 2003). As such, it remains to be determined how the brain computes time delays.

² Unlike the majority of DD studies, fMRI activity was recorded separately from a behavioural DD task.

1.2.3 Conclusions from neural accounts of intertemporal choice

The majority of evidence for neural mechanisms of intertemporal choice has come from animal paradigms, and therefore, drawing precise conclusions is cautioned. Whilst a neuroeconomic approach within humans has deconstructed components of decision making under uncertainty, a similar deconstruction of ITC has not been achieved. Given the paucity of human studies examining the neural representation of delays beyond the seconds to minutes range, it remains unclear as to how time delays and therefore delayed rewards are encoded and represented. On this note, it is worth pointing out that electrophysiological studies in animals have reported neuronal activity, either in specific structures or within the midbrain dopaminergic networks, which reflects parameters of reward magnitude, delay and value, *during* delay periods; i.e. they reflect the anticipatory aspects of delay. However, no such studies have been carried out in human subjects, primarily because intracranial recordings are not feasible. Nevertheless, electrophysiological methods for investigating human neural activity would provide a suitable methodological approach. Indeed, both ERPs and oscillatory activity have been applied to study various dimensions of impulsive behaviour³ (Alexander, et al., 2008; Chi, et al., 2005; Dimoska & Johnstone, 2007; Munro, et al., 2007). Additionally, EEG methods are especially adept for exploring the affective dimensions implied by observations of limbic activity in response to immediacy. As such, they may be more informative of both cognitive and affective processes involved during intertemporal decision making. Given that the debate between single versus multiple systems remains, alternative experimental paradigms within human DD studies may prove beneficial.

³ Predominantly impulsive inhibition, or ‘motor impulsivity’.

1.3 Research Aims & Objectives

“Why is it difficult to save for a pension or maintain a healthy diet?”

There is a vast literature supporting the view that intertemporal choices are challenging because future outcomes are discounted as a function of delay. However, what processes underlie delay discounting and thus drive choice behaviour remain unclear. A review of both behavioural and neural delay discounting research demonstrates that there are commonalities between decisions involving delays and decisions involving uncertainty. However, specific attempts to frame delays and delayed-outcomes as uncertainty are lacking.

This thesis aims to address this perspective by unifying choice components of time and uncertainty within a single framework that considers intertemporal choice *as* decision making under uncertainty using both electroencephalography (EEG) and behavioural data.

This is achieved through a series of objectives:

Objective 1: To what extent does delay discounting behaviour arise as a function of perceptions of uncertainty?

Previous associations between delay and probabilistic discounting are concerned with a common discounting function that underlies both types of choice. However, this does not address whether DD occurs because future outcomes are uncertain. Therefore, the first aim was to examine the extent to which DD behaviour reflects subjective perceptions of uncertainty. The specific questions addressed:

Are future outcomes perceived as uncertain? If so, do perceptions of uncertainty impact subjective value independently of considerations of time? (Chapter 2)

Are future time delays perceived objectively? (Chapter 3)

Objective 2: Is there a common neural mechanism for processing delay and uncertainty?

Previous neural approaches in both animals and humans have implicated dopamine in the processing of uncertain outcomes. Whilst animal studies have also suggested dopamine neurons encode delay features, human studies have not addressed how time delays are represented within the brain. Drawing a parallel with the electrophysiological approaches taken within the animal literature, Chapter 4 described the use of a reward processing paradigm to reason that the perception of delay is automatic and is associated with reduced emotional salience.

Objective 3: What makes a decision uncertain and how can this be reduced?

Although the future is uncertain in many dimensions, current theoretical and experimental paradigms have only accounted for uncertainty in terms of probability.

Adopting a framework of decision making under uncertainty which distinguishes between known (risk) and unknown (ambiguity) probabilities, a third objective was to explore how different types of uncertainty may be more reflective of future outcomes. The specific questions are:

Are future outcomes uncertain in terms of ‘if’ they will occur and ‘what’ they will consist of? And if so are they are different? (Chapter 5)

Can different types of uncertainty be reduced? (Chapter 6)

CHAPTER 2: The Future is Uncertain, But only for Gains: Perceptions of Outcome Uncertainty underlie Delay Discounting

2.1 Abstract

Time delays and uncertainty are inherently associated. However demonstrating this empirically has proved challenging. Given that the format in which uncertainty is presented influences subjective reward valuation, the current study tested the impact of framing future outcomes in terms of explicit uncertainties of outcome likelihood (UnO) or outcome utility (UnU) on delay discounting behaviour.

Across two experiments we highlight two important insights: 1) that delayed and uncertain outcomes are better described by a hyperbolic model based on a delayed outcome present certainty equivalent rather than expected value, suggesting uncertainty in outcome likelihood modulates the subjective value separately from considerations of time. 2) The perception of uncertainty underlies delay discounting of gains, whereas perceptions of certainty underlie the discounting of losses.

These findings suggest that gain-loss asymmetries in delay discounting may reflect the differential contribution of implicit assumptions regarding the likelihood of outcomes. Furthermore, our results suggest that time and uncertainty are not interchangeable, but are however mentally associated.

2.2 Introduction

Both human and non-human animals prefer outcomes that are delivered sooner rather than later, even when the delayed outcomes are rationally favourable. Such preferences can be accounted for by delay discounting (DD), which refers to the devaluation of subjective outcome value as a function of delay (Ainslie, 1975). However, the underlying cognitive processes which give rise to such devaluation remain unclear.

One consideration is that of uncertainty. Waiting for a delayed gain is inherently risky, as numerous factors may intervene to prevent its realisation (Green & Myerson, 1996; Sozou, 1998). In the same way that subjective value is modulated by delay, subjective value is also modulated as a function of outcome probability, with behavioural preferences for delayed and probabilistic outcomes modelled according to a hyperbolic function (Rachlin, Raineri, & Cross, 1991). The implication being that a common discounting mechanism underlies decision making with delayed and uncertain outcomes (Prelec & Loewenstein, 1991).

However, despite mathematical similarity and intuitive appeal, empirically establishing the relationship between time delays and uncertainty have produced contradictory findings. On the one hand, behavioural studies show that delayed gains are rated as increasingly uncertain (Patak & Reynolds, 2007; Reynolds, et al., 2007), that increasing time delays are associated with a reduction in the subjective probability of obtaining outcomes (Takahashi, Ikeda, & Hasegawa, 2007) and that low probability events are construed as more psychologically distant (Todorov, Goren, & Trope, 2007).

Conversely, correlations between behavioural preferences for delayed and probabilistic gains are often weak or non-existent (Ohmura, Takahashi, Kitamura, & Wehr, 2006; Olson, Hooper, Collins, & Luciana, 2007; Reynolds, et al., 2004). Similarly, attempts to localise shared neural mechanisms report distinct neural systems sub-serve choices involving time and uncertainty (Peters & Buchel, 2009; Weber & Huettel, 2008).

Collectively, such findings question the extent to which discounting as a function of time and uncertainty are associated phenomena (see Green & Myerson, 2004). In the current study this relationship is re-addressed by taking a novel perspective. We

consider that part of the problem may lie in the restricted conception of uncertainty along the single dimension of outcome probability (Kahneman & Tversky, 1982). This carries two relevant issues for relating delay and uncertainty within discounting research; the degree to which uncertainty is perceived, and the type of uncertainty considered.

2.2.1 Presenting and Perceiving Uncertainty

In drawing a parallel between delay and probability discounting in terms of behavioural assessment, the focus has been largely on demonstrating their shared hyperbolic form (Myerson, et al., 2003). Yet, the discounting of probabilistic gains represents a fundamentally distinct cognitive task from discounting by delay. Consider the following choices that represent typical examples from probability and delay discounting procedures respectively:

Choice 1: “Would you prefer £50 for sure or a 25 % chance of £100?”

Choice 2: “Would you prefer £50 now or £100 in 2 years?”

In both cases, depending on a decision maker’s response, the value of the certain/immediate gain is adjusted incrementally, until the two options are perceived as equivalent in subjective value. This process is repeated across a range of outcome probabilities and delays in order to define a subjective value curve for a given amount (i.e. £100 in the cases above) as a function of decreasing odds of delivery or delay (Rachlin et al., 1991).

Despite procedural similarities, these two choices differ in terms of information made available, and the required cognitive capacity to evaluate them. In choice 1, the explicit presentation of probabilities communicates information regarding the potential likelihood of a gain, and therefore, potential loss. Therefore, with increasing odds against receiving a reward, not only is there a risk that it may not be received, but there is also an added dimension of loss that is not explicitly present within a delay discounting procedures (Green, Myerson, & O’Donoghue, 1999; Prelec & Loewenstein, 1991).

When discounting by delay, as in choice 2, information regarding the likelihood that a gain outcome may not be received, and the potential for loss is not made explicitly available, but may not necessarily be absent from the decision process, i.e. there may be an implicit assumption that an outcome may not be received. In other words, decision makers may hold unconscious associations between future time points and the likelihood of outcomes being delivered or not (Keren & Roelofsma, 1995). Such unconscious ‘implicit’ associations play an influential role in outcome evaluations and decision processes (Dijksterhuis & Nordgren, 2006; Galdi, Arcuri, & Gawronski, 2008), and may also apply to subjective evaluations involving time (Patak & Reynolds, 2007).

This distinction between implicit and explicit uncertainty can be understood in terms of outcome information availability, or what economists have traditionally referred to as a distinction between risk and ambiguity (Keren & Gerritsen, 1999). For decisions under risk, a decision maker is provided with explicit probabilities regarding the likelihood of an outcome occurring. In contrast, a lack of information regarding such outcome probabilities defines ambiguous decisions. Empirical evidence shows that the degree of information availability affects the confidence a decision maker has in the likelihood of an outcome and thus influences their subsequent preferences (Curley, Yates, & Abrams, 1986; Einhorn & Hogarth, 1986). Therefore, providing information as to the likelihood of an outcome, i.e. making uncertainty explicit, is more informative and preferable than not, i.e. leaving outcome chances to the discretion of the decision maker.

Furthermore, available outcome information is susceptible to the mode in which it is presented. For example, the degree to which uncertainty is weighted within a decision can be shaped by a number of contextual variables, such as the format in which it is presented (Chapman & Liu, 2009; Gottlieb, Weiss, & Chapman, 2007; Reyna & Brainerd, 2008), valence dimension (Kahneman & Tversky, 1984; Shelley, 1994) and whether outcome likelihoods are expressed symbolically or extracted from experience (e.g. Hertwig & Erev, 2009).

Although it is less clear whether information availability concerning uncertainty has a direct impact on discount rates, several observations suggest this may be the case. For example, reframing gain outcomes according to specific calendar dates (Read, et al.,

2005) or contextualised with episodic imagery (Peters & Büchel, 2010) reduces discount rates for future gains by enhancing delayed outcome representations. Similarly, discount rates are also attenuated when participants are able to experience the outcomes of their choices (Lane, Cherek, Pietras, & Tcheremissine, 2003). Providing the opportunity to build action-outcome contingencies through experience may permit greater confidence that outcomes will be delivered (Barron & Leider, 2010). Therefore, task manipulations which provide information confirming an outcome's delivery may reduce the need for immediacy. In this respect, it is plausible that the format (i.e. explicit versus implicit) will have an impact on the rate of discounting (e.g. Keren & Roelofsma, 1995).

2.2.2 Types of Uncertainty

Whilst uncertainty may be defined in a number of ways (Lipshitz & Strauss, 1997) decision uncertainty is often considered along a single dimension of outcome likelihood, i.e. the probability of whether outcome *X* will occur (Kahneman & Tversky, 1982). However, for many real world decisions involving delayed rewards, a decision maker may not only be faced with the uncertainty of *if* a reward will be delivered or not, but also *when* a reward will materialise, and *what* type of reward stands to be gained (c.f. Herman & Polivy, 2003)

As previously noted, addressing the issue of *when* outcomes will be delivered proves to be an influential variable in behavioural preferences. For example, the date/delay effect reported by Read and colleagues emphasises the impact of reframing durations as specific dates on discounting behaviour. Whilst providing concrete outcome delivery points in the form of calendar dates may reflect the enhancement of future outcome representation and the concomitant underweighting of waiting duration (Read, et al., 2005), it is also possible that such framing reduces ambiguity about when outcomes will occur.

Uncertainties of '*if*' and '*what*' may be construed as reflecting the variability within decision parameters of outcome likelihood and outcome utility, both of which are highly influential to reward valuation (Chapter 5). As such, different types of uncertainties may play similar or distinct roles within future orientated decisions.

These two issues collectively highlight a fundamental point; the type of uncertainty and the degree to which this uncertainty may be implied is a task variable of delay discounting tasks that has been overlooked. Therefore, the primary goal of the current research was to examine the impact of framing delayed gains as explicitly uncertain in terms of ‘*if*’ and ‘*what*’ on discounting behaviour. This was achieved across two experiments which a) established a methodological protocol in terms of the assessment of delayed and uncertain outcomes (Experiment 1) and b) explored the generalisability of uncertainty as an account for the magnitude and sign effect (Experiment 2).

2.3 Experiment 1: Present certainty equivalents vs. expected value

2.3.1 Defining discount rates for delayed and uncertain outcomes

Only a few studies have attempted to combine information regarding outcome delay and probability within a single “package” (Ostaszewski & Bialaszek, 2010; Yi, de la Piedad, & Bickel, 2006), however, in these instances, when calculating discount rates, assessment has been made on the basis of objective amounts. To understand why this presents a problem, it is necessary to understand how discount rates for delayed outcomes are calculated.

Discount rates are typically assessed by presenting a series of forced choices between immediate (or sooner) and delayed outcome amounts (Tesch & Sanfey, 2008). This produces a series of indifference points, that when plotted, reveal a curve reflecting the devaluation of a gain as a function of time. A discount rate is obtained by modelling the curve with hyperbolic [$V = A / (1 + kd)$] or exponential [$V = Ae^{(-kd)}$] decay functions, where V represents the subjective value of the discounted gain A , after delay d , and k is the rate governing the degree of discounting. Alternatively, a model free method is to measure the area under the discount curve (AUC; Myerson, Green, & Warusawitharana, 2001).

Estimates of k and AUC require considering the position of indifference points relative to the objective amount presented (i.e. A in the above equations). This is reasonable when there is an assumption that only time is the intervening factor. However, as clearly demonstrated by probability discounting paradigms, the certainty equivalent of a

probabilistic outcome deviates from objective amounts, irrespective of time components (e.g. Rachlin et al., 1991). With this mind, the question to arise is whether individuals assess delayed and probabilistic outcomes in terms of a *present* certainty equivalent (PCE). To demonstrate this concept, consider the following two alternatives:

£100 after 1 year

50 % chance of £200 after 1 year

Both options are equivalent in terms of expected value (combined function of probability x magnitude; EV), yet may differ in their PCE. The present value of option 1 is unquestionably £100, and forms the initial starting point for discount curve analysis (i.e. A in decay functions). However, the present value of a 50 % chance of £200 in option 2 may vary. If risk averse, an individual may prefer a lower value present certainty equivalent, for example, £68. Whether discount rates reflect the devaluation of an outcome's EV or PCE is unclear. In the above example, this question may be addressed methodologically, by modelling discounting using decay functions where A represents either the expected value of £100 or the present certainty equivalent of £68. Modelling observed data with discount functions relies on non-linear regression, and produces indices of goodness of fit which may be used for comparison.

Although empirical evidence shows preferences deviate from expected values (Kahneman & Tversky, 1979) this has not been established within the context of delay discounting. Therefore, experiment 1 sought to establish whether discounting of delayed and uncertain gains follows expected or present certainty equivalents.

2.3.2 Method

2.3.2.1 Participants

Thirty-two University of Manchester (non-psychology/economics) students (15 males), mean age 24.2 (SD = 3.9) years, with normal or corrected-to-normal vision were recruited through an internal volunteer website on an opportunity basis. All participants signed a consent form approved by the local ethics committee.

2.3.2.2 Discounting conditions

Participants completed three computerised DD conditions consisting of a two-alternative forced choice format between small monetary gains available immediately and a larger gain available after some delay, and which defined the condition. The delayed gains were presented as: £100 (Standard condition representing the typical discounting procedure); a 50 % chance of £200 (Uncertainty in Outcome likelihood – UnO, representing the explicit representation of ‘*if*’ a reward might occur); and a 100 % chance of either: £50, £100 or £150 (Uncertainty in Utility- UnU, representing explicit presentation of ‘*what*’ reward will occur). A critical feature of all three conditions was that the expected values of the delayed gain outcome were equivalent (i.e. £100).

To converge at an indifference point (IPs), the point at which the immediate amount is subjectively equivalent to the delayed amount, an adjust-amount procedure was employed (Richards, Zhang, Mitchell, & de Wit, 1999). It has previously been shown that discounting functions are moderated by whether the smaller immediate amount is presented in either an ascending or descending manner (Robles & Vargas, 2008). Therefore, the current study employed a neutral strategy by initialising a choice trial where the smaller amount presented was half the value of the larger delayed outcome gain. For subsequent choices, the amount of the immediate gain was then adjusted based on the participant’s previous choice response. The size of adjustments (either an increase or decrease) made to the immediate gain amount were in accordance with a “half the difference” algorithm (See Du, Green, & Myerson, 2002). Therefore adjustments themselves were decreased with successive choices, with the first adjustment starting at half the difference between immediate and delayed gains. For subsequent choices, the size of the adjustments were half the previous adjustment, and

was repeated until the participant converged on the point of indifference. This procedure was repeated for each of eight delays (Now, 2 days, 30 days, 6 months, 1 year, 2 years, 5 years and 10 years), which were randomised within each condition. All discounting tasks and data collection were programmed using E-Prime software (Psychology Software Tools Inc., Pittsburgh, PA).

2.3.2.3 Procedure

Participants completed the three conditions in blocks each with its specific instructions to reflect the way the delayed gains were presented:

Standard condition: x amount now or £100 after t delay

UnO: x amount now or a 50 % chance of £200 after t delay

UnU: x amount now or a 100 % chance of £50 £100 or £150 after t delay

Before starting, participants were given a practice session to familiarise themselves with the procedure and how to make responses using the keyboard. Although no time limit on completing each condition was imposed, participants were encouraged not spend too long on each choice to prevent them from explicit calculations, and they were given 5-minute breaks between each task conditions. The experimental session lasted approximately 45 minutes, and on completion participants were debriefed and compensated with £5 for their time.

2.3.2.4 Analysis

Data was analysed using SPSS 15.0 statistical software. Individual indifference points under the standard discounting condition were assessed for non-systematic data as described by Johnson & Bickel (2008).

To assess the rate of discounting, hyperbolic [$V = A / (1 + kd)$] and exponential [$V = Ae^{(-kd)}$] discounting functions were fitted to group median and individual IPs observed for amount £100 across eight delays using non-linear regression analysis. For both group median and individual data, discount functions were fit on the basis of both expected values, where $A = £100$ and present certainty equivalents, which were

calculated for each participant based on IPs observed for ‘50% £200 Now’ (UnO) and ‘100 % £50, £100, £150 Now’ (UnU). To assess goodness of fit, R^2 values are typically reported to indicate the proportion of variance explained by the model. However, their application to non-linear regression has been shown to distort goodness of fit assessment (see Johnson & Bickel, 2008). Alternatively, goodness of fit measures that are based on the residuals (model fit error) of a model tested are not influenced by a comparisons to the mean of the data. Therefore, goodness of fit, and comparisons between the use of EV and PCE model fitting was determined on the basis of residual errors produced from non-linear regression analysis.

AUC values were used to provide a non-theoretically tied measure of discounting that would allow for statistical comparison across task conditions. Lower AUC values indicate steeper discounting, larger AUC values indicate less discounting. AUC calculation is also based on whether discounting is based on expected values or present certainty equivalents, and are thus reported once non-linear regressions identified appropriate discounting parameters.

2.3.3 Results

2.3.3.1 Goodness of Fit

One participant displayed non-systematic discounting under Standard conditions and was subsequently removed from all further analysis. Table 2.1 presents descriptive statistics for present certainty equivalents for each condition. As indicated, the average PCE values elicited under UnO conditions were lower in magnitude relative to the expected value of £100, whereas the average PCE values elicited under UnU conditions lay closer to the EV.

Table 2.1. Descriptive statistics for PCE values (£) observed for uncertain and delayed task conditions. PCE values were obtained for subjective values elicited in response to the larger uncertain outcome (UnO) or utility (UnU) option delivered at time point ‘now’.

	UnO	UnU
Mean	86.2	107.7
SD	46.2	28.1
Median	86.2	99.21
Range	45.2 – 174.9	75.8 – 180.1

Figure 2.1 presents the group median subjective values as a function of delay observed under each task condition. In order to facilitate comparison of discounting behaviour across task conditions, subjective values were calculated as proportions of delayed amounts. For group data, a hyperbolic function based on present certainty equivalents (PCE), provided a superior fit than when using expected value (EV) and an exponential function. Therefore, only curves representing a hyperbolic function fit to group median data are shown.

As indicated, there is a close alignment between Standard and UnO task conditions, which produce a steeper discounting curve, compared to UnU task conditions. Hyperbolic and exponential decay functions using both PCE and EV were also fitted to individual data across all task conditions, resulting in five curves for each participant (two each for UnO and UnU conditions, and one for Standard conditions).

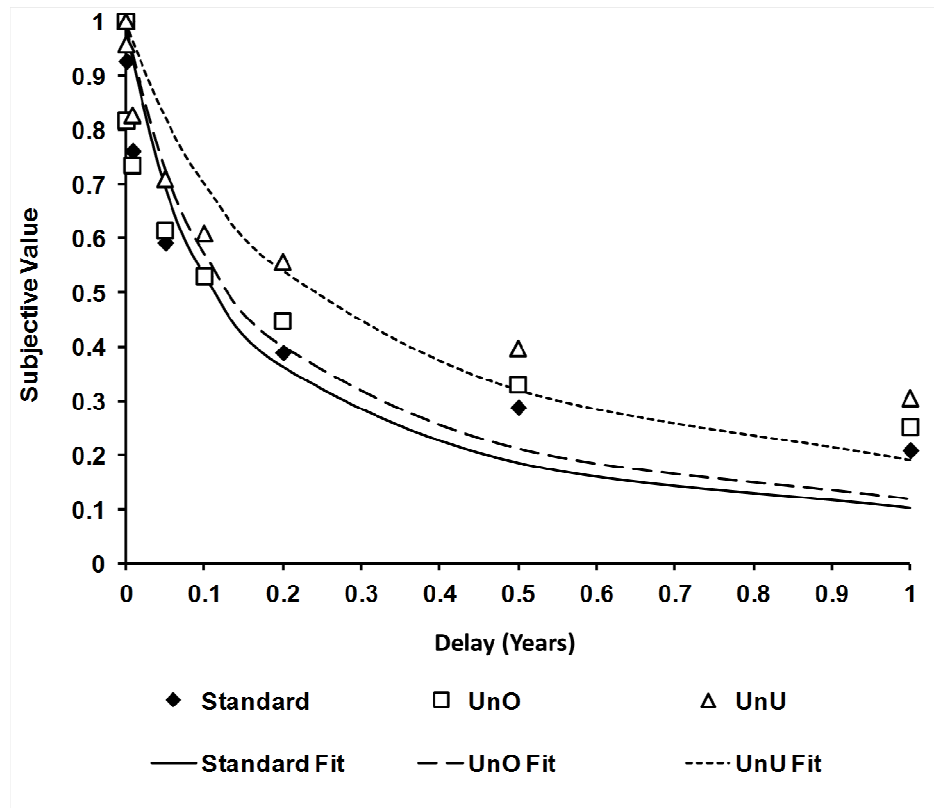


Figure 2.1. Subjective value as a function of delay for Standard, Uncertain Outcome (UnO), and Uncertain Utility (UnU). Symbols represent the group median subjective values expressed as proportions of the present certainty equivalent of delayed £100 (Standard), 50% chance £200 (Uncertain Outcome), and 100% £50, £100, £150 (Uncertain Utility). Curves represent a hyperbolic decay function based on present certainty equivalents which provided best fit of observed data.

Within-subjects comparison of residual errors produced from non-linear regression with a hyperbolic function using PCE and EV were made using Wilcoxon signed ranks tests. The pattern of individual results was similar to that observed at the group level. Median residual errors produced by hyperbolic functions based on EV and PCE across task conditions are presented in Figure 2.2 A. As indicated, greater residual errors were produced when using EV compared to PCE for both UnO, $z(31) = -3.30, p < .001$, and UnU conditions, $z(31) = -3.7, p = .001$.

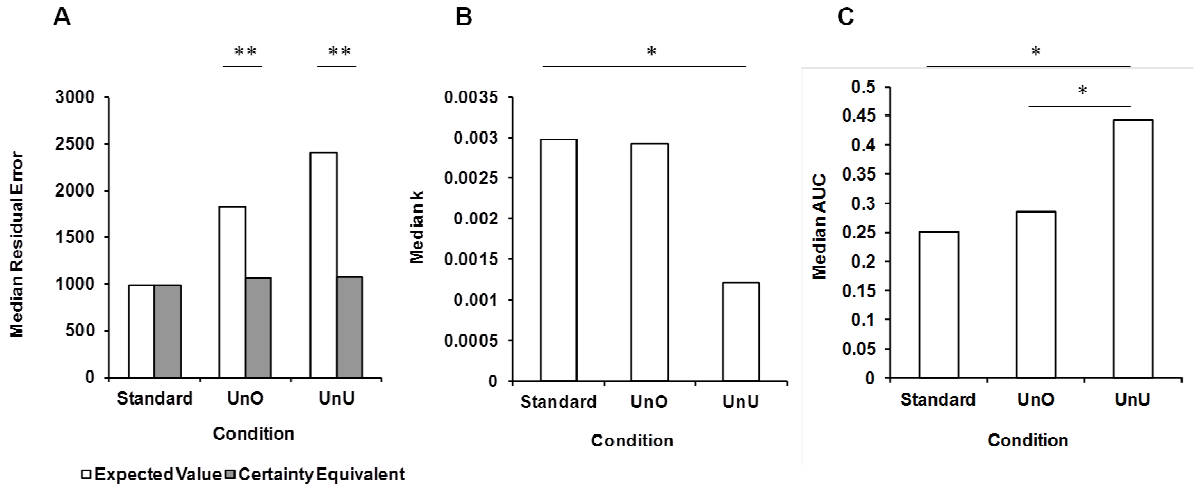


Figure 2.2. Hyperbolic modelling using expected values and present certainty equivalents. A) Mean residual errors produced by fitting hyperbolic decay functions for £100 delayed rewards, based on expected values and present certainty equivalents. As indicated, hyperbolic functions based on present certainty equivalent produce lower residual errors for rewards that are delayed and uncertain in outcome (UnO) and utility (UnU). B) Comparison of discount parameter k resulting from hyperbolic function based PCE across task conditions. Larger k indicates steeper discounting, small k indicates less discounting. As shown, UnU conditions elicit smaller k , compared to both Standard and UnO conditions. C) Comparison of AUC values calculated based on PCE across task conditions. Larger AUC values indicate less discounting, smaller AUC values indicate steeper discounting. * $p < 0.05$, ** $p < 0.01$ Bonferroni corrected for multiple comparisons.

2.3.3.2 Effect of Condition

Having established discounting of delayed and uncertain rewards are best approximated using a hyperbolic function based on PCE, individual k parameters were compared across task conditions using Wilcoxon signed rank paired test. As indicated in Figure 2.2 B, k resulting under Standard and UnO conditions are indistinguishable, $z(31) = -.89$, $p = .34$. UnU conditions however produced smaller k values compared to Standard conditions, $z(31) = -2.8$, $p = .005$, although the difference with UnO conditions only approached significance, $z(31) = -1.9$, $p = .054$.

To confirm this pattern of results, AUC values based on PCE were calculated for individual data. Both AUC and Log AUC values remained skewed (Shapiro Wilks $p < .05$), therefore, comparisons between AUC values were made using Wilcoxon Signed Ranks test. Figure 2.2 C illustrates median AUC values elicited across task conditions for both small and large gains. As indicated, Standard and UnO conditions elicited comparable AUC values, $z = -.84$ $p = .40$, whereas AUC values elicited under UnU conditions were significantly larger than those produced under standard conditions, $z = -2.9$, $p = .004$, and under UnO conditions, $z = -2.4$, $p = .016$).

2.3.4 Discussion of Experiment 1

The primary objective of Experiment 1 was to establish a methodology for assessing discount rates for delayed and uncertain gains. Specifically, we posed the question of whether delayed and uncertain gains are discounted according to expected value (EV) or present certainty equivalents (PCE). Results show that employing a hyperbolic function based on present certainty equivalents (PCE) provided a superior fit for delayed and uncertain gains compared to a hyperbolic function based on expected values (EV) at both a group and individual level. This is consistent with the general notion that subjective values for probabilistic gains deviate from expected values (e.g. Kahneman & Tversky, 1979).

Having established PCE provided a better approximation of discounting for delayed and uncertain gains allowed for comparison across task conditions. Comparisons of both AUC and k values revealed no significant differences between Standard and UnO conditions. Conversely, larger AUCs and smaller k values indicative of less discounting were elicited under UnU compared to Standard conditions. These observations imply the steepness of discounting may arise as a function of *implicit* uncertainty in outcome likelihood. However, it should be noted that guaranteeing the delivery of a delayed gain (100 % certainty) under UnU conditions did not abolish discounting altogether. This suggests outcome likelihood moderates the impact of time delays in producing overall discounting behaviour, and is consistent with the distinction made between time discounting and time preference (Frederick, Loewenstein, & O'Donoghue, 2002).

2.4 Experiment 2: Perceptions of uncertainty, magnitude and sign effects

Results from Experiment 1 suggest that delayed gains are discounted because they incorporate outcome likelihood at the point of outcome representation prior to considerations of delay. If our interpretations are correct, the same results should withhold when different sized amounts are employed, and when outcomes are both gains and losses (Green & Myerson, 2004). To further explore this notion we repeated Experiment 1 with two additional dimensions; outcome magnitude (small £100 vs. large, £1000) and outcome valence (gain vs. loss) with the following predictions:

Converging evidence shows that gain amount differentially affects delay and probabilistic discounting. Smaller delayed gains are discounted more steeply than larger delayed gains, whereas the reverse is true when gains are discounted as a function of outcome probability (Myerson, et al., 2003). If our interpretation that delayed and uncertain gains are discounted according to time not probability, the magnitude effect (steeper discounting for smaller relative to larger delayed gains) would be expected across all task conditions. Specifically, we predicted that for both small and large gains, rates of discounting would be equivalent between UnO and Standard conditions, and less steep for UnU relative to both standard and UnO conditions, and that overall, larger gains would be discounted less steeply than smaller gains.

With respect to discounting of losses, although less well studied, two general observations can be made. Firstly, studies have shown delayed losses are discounted less steeply than delayed gains (Murphy, Vuchinich, & Simpson, 2001; Thaler, 1981), and that manipulations of outcome magnitude are restricted to gain domains only (Estle, Green, Myerson, & Holt, 2006; Holt, Green, Myerson, & Estle, 2008; Mitchell & Wilson, 2010). Adopting the view from decision making under risk, the tendency for losses to ‘loom’ larger than gains (Kahneman & Tversky, 1979) is often proposed to underlie the gain-loss asymmetry. However, whether individuals perceive delayed losses as more certain or simply more salient is unclear. We suggest the former, hypothesising the reduction in discounting for delayed losses arises from the incorporation of *certainty* into valuations. From this perspective, we expected discounting behaviour elicited under Standard and UnU conditions to be equivalent.

2.4.1 Method

2.4.1.1 Participants

Sixty University of Manchester (non-psychology/economics) students (30 males) mean age 21.7 (SD = 4.1) years were recruited via the internal volunteer website on an opportunity basis. All participants had normal or corrected-to-normal vision, and it was ensured that participants recruited had not taken part in Experiment 1. All participants signed a consent form approved by the local ethics committee.

2.4.1.2 Discounting Conditions and Procedure.

The task design and procedures replicated Experiment 1, however, to prevent potential confounds resulting from completion of multiple discounting tasks, participants completed discounting tasks over two experimental sessions with a minimum of two weeks interval between sessions. In one experimental session, participants completed three DD conditions (Standard, UnO, UnU, counterbalanced) with small and large gains. In the second session, the same procedure was followed, however with delayed losses (again, counterbalanced across participants).

2.4.2 Results

2.4.2.1 Goodness of fit for delayed and uncertain gains & losses

Table 2.2 presents descriptive statistics for present certainty equivalents for each task condition by outcome valence and amount. As indicated, the average PCE values elicited under UnO conditions were lower in magnitude relative to expected values for both small (£100) and large (£1000) gain outcomes, whereas the average PCE values elicited under UnU conditions lay closer to the EV, replicating the results in experiment 1. For loss outcomes, PCE values for all task conditions and amounts were closer to the expected values, although, those elicited for UnO task conditions were somewhat higher in magnitude relative to UnU conditions.

Table 2.2. Descriptive statistics for PCE values (£) observed for uncertain and delayed task conditions by outcome valence (gain/loss) and amount (small/large). PCE values were obtained for subjective values elicited in response to the larger uncertain outcome (UnO) or utility (UnU) option delivered at time point ‘now’.

		Mean	SD	Median	Range
Gain	UnO (£100)	68.3	32.0	74.2	31.8 - 115.9
	UnO (£1000)	639.3	386.6	682.3	130 – 1699.2
	UnU (£100)	97.6	26.0	99.2	68.4 – 175.2
	UnU (£1000)	923.1	284.6	992.0	369.0 – 1495.2
Loss	UnO (£100)	112.4	29.3	102.9	31.8 – 199.9
	UnO (£1000)	1139.8	300.9	998.8	331.3 - 2000
	UnU (£100)	101.4	22.4	99.2	50.9 – 150.3
	UnU (£1000)	1006.3	257.1	992.0	79.9 – 1695.5

Table 2.3 shows the descriptive statistics of residual errors produced from hyperbolic non-linear regression based on EV and PCE for individual data across all task conditions, amounts and valences. As indicated by smaller residual errors, a more superior fit to observed data was achieved using present certainty equivalents compared to expected value, replicating results of Experiment 1.

Table 2.1. Descriptive statistics and Wilcoxon Signed Ranks comparisons for hyperbolic EV and PCE residual errors across task \times amount \times valence conditions

			Expected Value		Present Certainty Equivalent		Z
			Mean	Median	Mean	Median	
Gain	Outcome	£100	4846.625	3634.61	954.2648	657.771	-6.22**
		£1,000	462127.5	289562.6	96804.82	57808.17	-5.9**
	Utility	£100	2175.173	1197.451	1529.156	949.871	-2.22*
		£1,000	322962.2	146369.8	122118.9	63541.7	-3.55**
Loss	Outcome	£100	1412.141	5271.055	1091.65	1736.808	-2.31*
		£1,000	128699	359615.3	69048.15	124501	-3.56**
	Utility	£100	1062.641	1744.026	558.164	1067.567	-3.22**
		£1,000	77965.67	178180.8	49232.21	96246.83	-2.79*

* $p < 0.05$, ** $p < 0.01$, Bonferroni corrected for multiple comparisons

2.4.2.2 Comparison between delayed and uncertain gains and losses

Figure 2.3 shows the group median subjective values (expressed as a proportion to facilitate comparison) plotted as a function of delay across the three delay discounting conditions for small (£100, top panel) and large (£1,000 bottom panel) delayed gains and losses (only curves representing a hyperbolic function using PCE are shown).

As indicated, delayed losses are discounted less steeply compared with delayed gains across all task conditions and a differential effect of magnitude can be observed for gains and not losses that is consistent with previous studies. However, examination of the right panel of Figure 2.3 shows differential effect of magnitude for delayed losses which are uncertain in outcome.

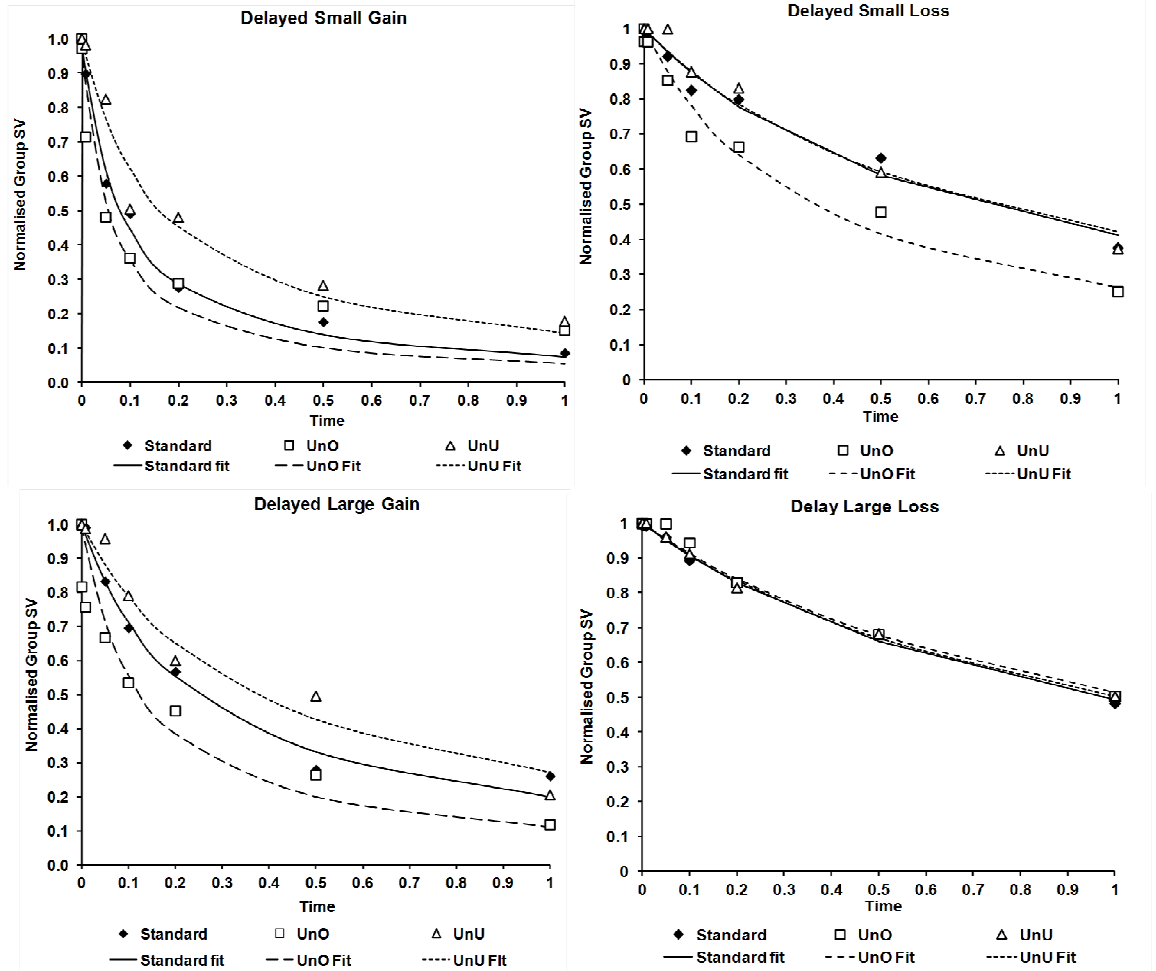


Figure 2.3. Group median subjective value as a function of delay: comparison across valence, magnitude and task condition. Symbols represent group median indifference points expressed as a proportion of present certainty equivalent for small £100 (upper panel) and large £1000 (lower panel) delayed gains and losses. Curves represent group median subjective values fit with a hyperbolic decay function based on present certainty equivalents for each task condition: Standard, Uncertain Outcome (UnO); Uncertain Utility (UnU).

A significant main effect of valence confirmed delayed losses were discounted less steeply (i.e. larger AUCs) than delayed gains, $F(1, 59) = 20.39, p < .001, \eta_p^2 = .30$. A significant main effect of DD condition, replicated results of Experiment 1, $F(2, 118) = 8.10, p < .001, \eta_p^2 = .12$. Pair-wise comparisons corrected for multiple comparisons show this effect was driven by larger AUC values elicited by UnU relative to Standard, ($p = .02$), and UnO conditions, ($p = .001$), with no differences observed between Standard and UnO conditions, ($p = .64$). However, the analysis revealed a significant valence x DD condition interaction, $F(2, 118) = 5.17, p = .007, \eta_p^2 = .08$, and is depicted in Figure 2.4. As indicated for gains, AUC values did not differ between Standard and UnO conditions, $t(59) = -1.13, p = .26, d = .15$, yet did differ significantly between Standard and UnU conditions, $t(59) = -4.15, p < .001, d = .41$, consistent with the results of Experiment 1. For losses, this pattern was reversed, with AUCs showing equivalence between Standard and UnU conditions, $t(59) = -.043, p = .67, d = .05$, yet differed significantly between Standard and UnO conditions, $t(59) = 2.80, p = .007, d = .40$.

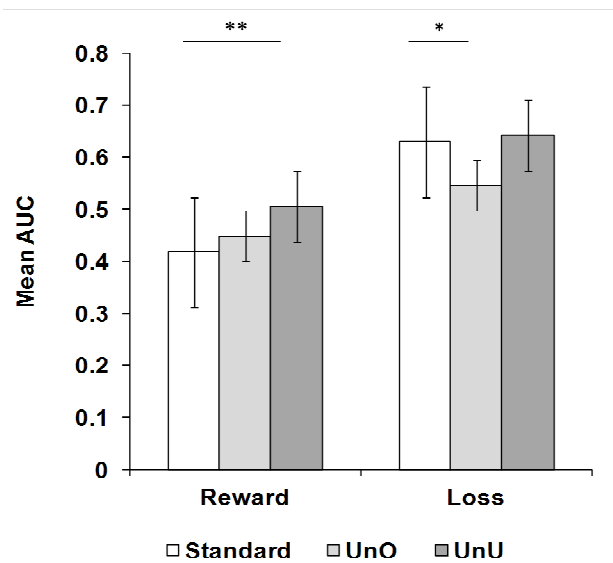


Figure 2.4. Mean AUC valence x task condition interaction. Mean AUC values collapsed across large and small amounts for Standard, Uncertain Outcome (UnO) and Uncertain Utility (UnU) task conditions. Error bars indicate ± 1 S.E.M., ** $p < .001$, * $p < .05$, Bonferroni corrected for multiple comparisons.

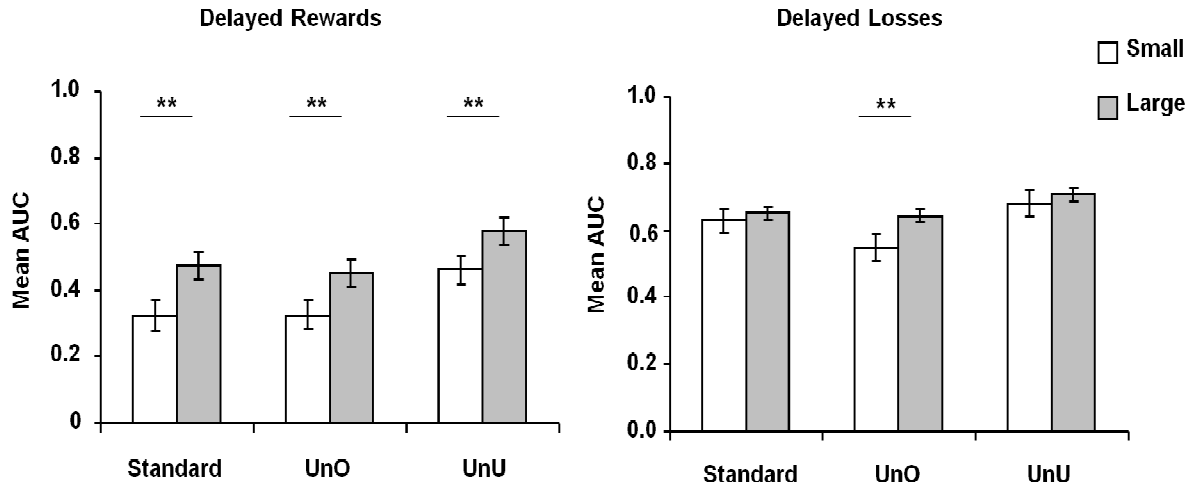


Figure 2.5. Mean AUC valence \times task condition \times amount interaction. Mean AUC values for delayed rewards across task condition (left) show significant differences between small and large delayed amounts. Conversely, Mean AUC values for delayed losses across DD conditions (right) only show magnitude differences for delayed and uncertain outcome losses, with smaller losses discounted more steeply than larger losses. Note, AUC values range from 0 – 1.0; lower values indicating steeper discounting. Comparison of rewards and losses shows smaller AUCs, i.e. steeper discounting of rewards. Error bars indicate + standard error of the mean. * $p < .05$, ** $p < .01$.

The repeated ANOVA also revealed a significant main effect of magnitude, $F(1, 59) = 58.01$, $p < .001$, $\eta_p^2 = .50$, with larger AUC values elicited by larger delayed outcomes. However, a valence \times magnitude, $F(1, 59) = 15.52$, $p = .001$, $\eta_p^2 = .21$, and an overall interaction between valence \times amount \times task, $F(2, 118) = 4.08$, $p = .019$, $\eta_p^2 = .07$, revealed the effect of magnitude was restricted to discounting of gains (post-hoc paired t-tests between AUCs for small and large gains across DD conditions, were all below $p < .001$), and discounting of delayed and UnO losses $t(59) = -4.2$, $p < .001$ (see Figure 2.5).

2.4.3 Discussion of Experiment 2

Consistent with discounting literature, the analysis revealed main effects of valence and amount, with delayed gains discounted more steeply than delayed losses, and smaller gains discounted more steeply than larger gains. However, interactions between valence, amount and DD condition revealed two important insights regarding the impact of uncertainty framing.

Firstly, AUC values reflecting the discounting of delayed and uncertain gains were consistent with those observed in Experiment 1; that is, framing delayed gains as uncertain in terms of outcome likelihood did not affect the rate of discounting compared to Standard task conditions. Conversely, framing delayed gains as uncertain in utility yet certain in outcome likelihood reduced discount rates. These observations were maintained across gain amounts. However, this was not the case for delayed losses. Rather, AUC values elicited under Standard task conditions were more closely aligned with UnU task conditions, both of which were larger than AUC values elicited under UnO conditions.

Secondly, steeper discounting for smaller compared with larger outcomes was observed for gains only, consistent with previous reports that losses are less sensitive to changes in outcome magnitude (Estle, et al., 2006; Mitchell & Wilson, 2010). However, the interaction between valence, amount and DD condition revealed the presence of a magnitude effect for delayed losses framed as uncertain in outcome likelihood; specifically, smaller delayed and probabilistic losses were discounted more steeply than larger delayed and probabilistic losses.

2.5 General Discussion

The present study is the first to examine the effect of framing delayed outcomes in terms of explicit uncertainty on delay discounting behaviour, and also the first to address the issue of how delayed and uncertain outcomes are methodologically assessed. Taken together, results from both Experiments 1 and 2 draw a parallel between decision making under uncertainty and decisions involving time. In doing so, our data reveal uncertainty impacts delay discounting processes both at the point of outcome representation and the degree to which outcomes are devalued.

2.5.1 *Assessment of discounting for delayed and uncertain outcomes*

Previous self-report based studies indicate that participants incorporate uncertainty in to their evaluations of delayed gains (Patak & Reynolds, 2007). However, previous studies addressing the relationship between delay and uncertainty have relied on correlations between delay and probabilistic discounting tasks (e.g. Estle, et al., 2006; Holt, Green, & Myerson, 2003; Mitchell & Wilson, 2010; Reynolds, et al., 2004). This is problematic, given the fundamental differences in task structure.

The current study sought to re-address this issue by focusing on the framing of uncertainty that accompanies delayed gains. However, to achieve this required a consideration of how discount rates for delayed and uncertain outcomes are assessed. Regardless of the manner in which DD tasks are administered (for a review see Smith & Hantula, 2008), the rate of discounting is derived by eliciting indifference points, (i.e. the point at which an immediately available amount is subjectively equivalent to a counterpart delayed amount) between successive smaller sooner and larger delayed choice pairs (Tesch & Sanfey, 2008). As delay discounting procedures consist of descriptive choices, there is an assumption that the amount of a delayed outcome is perceived objectively. That is, when calculating the subjective value of a delayed gain, using either AUC or discount parameters such as k , indifference points are considered as a function of the total gain amount *objectively* presented.

However, probability distorts subjective value, such that probabilistic outcomes have subjective certainty equivalents (e.g. Tversky & Kahneman, 1982), which is the essence of probabilistic discounting. Here, we extend this proposition to consider delayed and uncertain outcomes to have subjective *present* certainty equivalents. Methodologically, the assumption that delayed and uncertain outcomes are devalued according to their expected value overestimates the true rate of discounting. Results from both Experiment 1 and 2 revealed this is indeed the case. Hyperbolic discount functions based on present certainty equivalents for delayed and uncertain outcomes provided a more superior fit to both group and individual data.

Considering delay discounting according to present certainty equivalents is relevant for methodological and theoretical reasons. Firstly, it provides a novel approach for addressing the relationship between delay and uncertainty that avoids making comparisons across separate discounting tasks. Secondly, it suggests the impact of uncertainty on DD processes may lie in how outcomes are represented prior to any influence of time. This is consistent with previous suggestions that evaluating future risky prospects follows a two-stage process (Keren & Roelofsma, 1995; Öncüler & Onay, 2009; Weber & Chapman, 2005), and is further supported by our comparisons across DD conditions.

2.5.2 Implicit uncertainty underlies discounting of gains

Experiments 1 and 2 revealed Standard and UnO conditions generated equivalent rates of discounting (assessed by both AUC and k measures). According to delay discounting processes, smaller amounts are discounted more steeply than their larger counter parts (i.e. individuals choose more impulsively for smaller gains). Conversely, when discounting as a function of probability, smaller amounts are discounted less steeply. However, despite present certainty equivalents for delayed and uncertain gains being lower in magnitude relative to the standard amounts (e.g. £100/£1000, see Tables 2.1 & 2.2), neither of these phenomena were observed. This suggests that under Standard conditions, there is an *implicit* consideration of outcome likelihood, which impacts the perception of delayed gain outcomes, and is consistent with self-reported data (Patak & Reynolds, 2007).

Comparisons between Standard and UnU conditions are also consistent with this view. Our initial intention was to examine the impact of uncertainty in outcome utility; that is, not knowing *what* reward would be received, distinct from the uncertainty relating to *if* a reward would be received. To maintain a degree of consistency in both expected value and presentation format across DD conditions, we compromised on three possible outcomes (e.g. £50, £100, £150). As such, the mean, median and expected value of delayed UnU gains were equivalent to the objective amount available under the Standard conditions. It is most likely that, given that all three potential outcomes are visible, the objective (and expected value) amount of £100 emerges as the most salient feature; it is perhaps not surprising then, that participant's present certainty equivalent for a delayed and Uncertain Utility gain closely approximated the expected value (e.g. Kahneman & Tversky, 1972). In this respect, our methodological approach towards creating an uncertainty in utility may not have been successful. Nevertheless, because UnU PCEs were so closely aligned with the objective amount of the Standard condition, these two conditions differed primarily in the degree to which outcome likelihood was explicitly addressed. That both k and AUC values were significantly reduced/increased respectively (i.e. indicating less impulse choice) under UnU conditions suggests the steeper discounting evoked by Standard conditions reflects the weight of *implicit* outcome uncertainty. Additionally, it is worth pointing out that guaranteeing the delivery of a delayed gain under UnU conditions did not completely abolish devaluation over time. This would suggest that whilst uncertainty looms within choices for delayed gains, the removal of uncertainty allows considerations such as waiting costs to dominate choice (Keren & Roelofsma, 1995).

Therefore, where future outcomes relate to rewarding outcomes, subjective reward value is constructed considering that outcome gains *may not be* delivered. This raises the question as to whether an immediacy bias is driven by the aversion to the implicit uncertainty *per se* or the potential loss that assumed uncertainty may imply?

2.5.3 *Implicit certainty underlies attenuated discounting for losses*

It has been consistently reported that delayed losses are discounted less steeply compared with delayed gains (Chapman, 1996; Murphy, et al., 2001; Ohmura, Takahashi, &

Kitamura, 2005). At the same time, within descriptive choice contexts, losses promote risk seeking, whereas gains promote risk aversion (Kahneman, & Tversky, 1979). However, delay discounting of losses is less well studied, and the notion that attenuated discounting of delayed losses may reflect risk-seeking tendencies has received little attention. Our examination of discounting behaviour with delayed and uncertain losses are therefore both novel and revealing.

When compared with delayed gains, the current data support the general observation of reduced discounting for delayed losses. However, interactions with both outcome amount and DD conditions revealed a more complex story. Firstly, an interaction between valence and DD condition revealed that whilst discount rates were indistinguishable between Standard and UnO conditions for delayed gains, this was not the case for delayed losses. Rather, discount rates elicited under Standard conditions were more closely aligned with those elicited under UnU conditions.

This observation suggests that where future outcomes relate to potential losses, individuals would appear to incorporate the certainty that a loss outcome will occur into their subjective evaluation; that is, delayed subjective loss value is constructed considering that outcome losses *will* occur.

Secondly, unlike Standard and UnU conditions, losses framed as uncertain in outcome likelihood did appear to be susceptible to magnitude effects. Specifically, smaller delayed and probabilistic losses were discounted more steeply than larger delayed and probabilistic losses. This observation is difficult to reconcile with the previous studies that show a less reliable effect of magnitude on losses that are either delayed or probabilistic (Baker, et al., 2003; Estle, et al., 2006; Mitchell & Wilson, 2010). However, a sufficient explanation regarding the magnitude effect and asymmetry between gain and loss discounting is still desired (Mitchell & Wilson, 2010). As such, our magnitude effect for delayed and probabilistic losses may hold some merit.

Reduced discounting for delayed losses can be accounted for by a steeper value function for losses compared to gains, i.e. losses loom larger than gains (Kahneman & Tversky, 1979). As such, individuals will always seek to minimise a loss, which translates to

preferences for a small loss now, as opposed to a larger loss in the future. Due to the nature of the adjust-amount procedures DD tasks employ, obtained indifference points will lie closer to the loss amount which is delayed, and consequently, produce shallower discount curves. However, the size of the loss is negligible as the situation is always the same; choice in order to avoid the greater loss.

Within the current study, by framing a delayed loss as a 50 % chance, it is possible that the potential for loss was offset by the equal possibility that no loss would transpire. Considering delayed losses are perceived as certain, the possibility for no loss may have inadvertently been perceived as a positive outcome (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001) and thus susceptible to differences in magnitude. Indeed, recent findings suggest a magnitude effect emerges for delayed losses when such losses are described as transactions, because with transaction costs there is always an explicit emphasis on the corresponding gain to be obtained (Jones & Oaksford, 2011). Given this is the first study to examine framing delayed outcomes in terms of explicit uncertainties, further research examining this notion is warranted.

Nevertheless, the current study demonstrates the degree to which uncertainty is made explicit as opposed to being implicitly assumed is a relevant task variable that may account for variation in discounting rates traditionally observed. Two additional insights offered concern the impact of time and the type of uncertainty.

As previously mentioned, removing uncertainty did not abolish discounting. We have attributed this observation as reflecting the ‘cost of waiting’ or time preference per se. Indeed, elsewhere it has been shown that the extent to which time perspectives are accounted for by DD procedures is highly task dependent (Read et al., 2005; Chapter 3). Therefore, whilst the current data suggest an implicit relationship between time and uncertainty, independently, these components appear to impact judgments about the future in distinct ways (Frederick, et al., 2002). Interestingly, recent studies based on alternative choice paradigms have arrived at the same conclusion (Epper, Fehr-Duda, & Bruhin, 2011).

In terms of the type of uncertainty, whilst outcome likelihood and not utility proved more influential, this may have reflected the compromise of choosing only three outcome amounts. Indeed, dimensions of choice set size have been found to modify judged certainty equivalents (Stewart, 2009). Given outcome likelihood modifies delayed outcome representation, creating a greater variability in delayed outcome utility may provide a noteworthy feature to consider in subsequent research.

In this respect, it is also worth reflecting on the values chosen to represent UnO conditions. One of the incidental effects of rejecting an exponential account of discounting has been the discouragement that delay and risk are somehow associated. Accordingly to an exponential model, the rate of subjective devaluation is constant, underscored by a constant hazard rate, i.e. probability that some event will prevent a reward outcome (Green & Myerson, 1996). Despite the superiority of a hyperbolic model over an exponential one, the notion that increasing time delays should equate with increasing risk has nevertheless remained. However, this may not be always be the case. Although we chose ‘a 50 % chance’ to construct our UnO condition, it is not clear whether probabilities above and below would have a similar or differing impact. Indeed, it is plausible that specifying an objective probability is irrelevant. For example, an implicit assumption that a future gain/loss is uncertain/certain may fall within the premise that “*if it’s delayed its uncertain*” heuristic. Within risky decision contexts, ‘take-the-best’, or ‘recognition’ heuristics present as strategies employed to make “fast and frugal” decisions, particularly where information may be either missing, or too costly to search for (Gigerenzer & Gaissmaier, 2011). Again, given the novelty of the current study, these are possibilities which require further investigation

2.6 Conclusion

The current findings suggest implicit associations regarding the delivery of delayed outcomes contribute towards the rate of discounting. Further, the impact of such associations is modulated by outcome valence, and may underlie asymmetries in the discounting of gains and losses previously observed. Specifically, the steepness of delay discounting for gains arises from the incorporation of *uncertainty* in outcome likelihood into subjective valuation. Conversely, the attenuation of delay discounting for losses

arises from the incorporation of *certainty* in outcome likelihood into subjective valuation. Our results also tentatively suggest time and uncertainty may exert their impact independently. As delayed outcomes are discounted according to present certainty equivalents rather than their expected value suggests an immediacy bias is set prior to discounting by time. As noted by previous attempts to resolve immediacy-certain interactions (e.g. Keren & Roelofsma, 1995; Weber & Chapman, 2005), there are multiple routes through which uncertain and delay attributes influence preference, thus a complete picture of the relationship between time delays and uncertainty is further warranted.

CHAPTER 3: Estimating Time Intervals in the Context of Intertemporal Choices

3.1 Abstract

In humans, representation of the future is susceptible to the way time delays are presented, temporal orientation and appreciation of future consequences. Thus commonly used adjusting-amount procedures may not fully reflect the impact that time has on subjective value. We demonstrate that delay discounting (DD) based on adjusting-time results in significantly steeper discounting rates than when based on adjusting-amount. Further, we show that discounting obtained by adjusting-time is better correlated with variation in self-reported consideration for future consequences. These findings suggest that DD task procedures based on the estimation of time intervals may enhance attention towards waiting that is underweighted when procedures are based on estimating subjective values; the result is the steepening of delay discounting. This is consistent with the view that individuals do not perceive future durations objectively, and suggests DD-T tasks are better reflective of individual's future orientation.

3.2 Introduction

Given the choice between rewards available at different time points, both human and non-human animals act impulsively, preferring smaller rewards available sooner over larger rewards that are delayed. Such preferences can be described in terms of delay discounting (DD), which refers to the subjective devaluation of rewarding outcomes as a function of the time delay until their receipt (Ainslie, 1975).

The DD framework is often used as a behavioural index of impulsivity. Steeper discounting of future rewards reflects greater impulsivity, and is observed across a number of maladaptive behaviours that place a premium on immediate gratification, such as gambling, substance use, smoking and obesity (Bickel, et al., 2007; Reynolds, 2006; Weller, et al., 2008). The same populations also show alterations in their perception of experienced and imagined time. For example, impulsive populations tend to overestimate time intervals within the second to minutes range (Berlin, Rolls, & Kischka, 2004; Wittmann, et al., 2007). Similarly, such populations also exhibit distortions in the way they mentally represent the future, displaying shortened temporal horizons relative to healthy controls (Hodgins & Engel, 2002; Petry, Bickel, & Arnett, 1998). These observations would suggest an association between delay discounting and the perception of psychological time (experienced and imagined) (Kim & Zauberman, 2009; Takahashi, et al., 2008; Wittmann & Paulus, 2009b). However, to what extent DD procedures that estimate discounting rates are sensitive to individual's temporal orientations is unclear.

In this paper we argue this lack of clarity may reside in methodological issues in the way DD rates are calculated. By integrating two alternative DD approaches based on perceived-value and perceived-time we propose a single methodological framework that addresses the role of future temporal horizons in DD.

3.2.1 Discount curves and discount rates

The rate at which future outcomes are discounted can be assessed experimentally using psychophysical procedures that adjust either the delay (Mazur, 1987) or the reward amount (Rachlin, Raineri, & Cross, 1991). In both cases, a series of choices between a smaller reward available immediately, and a larger reward available after some time delay are presented. The objective is to find the indifference point (IP) between the two alternatives, where both options are perceived to be equivalent.

Under adjust-amount procedures (DD-A), IPs are reached by adjusting the amount of immediate reward incrementally until it is perceived as subjectively equivalent in value to the larger delayed amount (Rachlin, et al., 1991). Repeating this process across a range of delays produces a series of IPs which are plotted to reveal a subjective value curve for a given reward amount. Fitting these points with a decay function [hyperbolic or exponential], or estimating the area under the curve (AUC) are then used to calculate the rate of discounting (Tesch & Sanfey, 2008). Alternatively, under adjust-time procedures (DD-T), all amounts are held constant, and the IP is arrived at by incremental adjustments to the time until the two amounts are perceived to be equivalent in value (Mazur, 1987). A critical point to note here is that a single discount rate (whether obtained by fitting decay functions or AUC) is obtained for a given outcome amount over a specified range of delays and is determined by the shape of the discount curve.

Theoretically, if the subjective value of a delayed reward reflects only the combined function of time and amount components, then no systematic differences between DD-A and DD-T procedures should emerge. Indeed, comparison of both procedures in non-human animals has shown they produce equivalent forms (hyperbolic) and rates of discounting (Green, Myerson, Shah, Estle, & Holt, 2007). However, since the predominant mode of assessment of DD in humans is DD-A, it is unclear if the two tasks remain equivalent. In fact, evidence suggests that the two procedures should produce differences in discount rates. It is this evidence that forms the basis for our argument that DD-A and DD-T procedures will reflect respective contributions of perceived-value and perceived-time accounts that underlie discounting.

3.2.2 Perceived-value: discounting future utility

Early studies using the delay of gratification paradigm demonstrated that waiting for a larger more preferable reward was undermined by attending to the ‘hot’ features attributed to a smaller yet more temporally proximal reward (e.g. Metcalfe & Mischel, 1999). This view that temporal proximity confers enhanced cognitive representation is captured by theoretical accounts of intertemporal choice that suggest time engenders an affective gradient between more immediate outcomes that are more emotionally salient compared to delayed outcomes that are intangible (Rick & Loewenstein, 2008). Similarly, Construal level theory (Trope & Liberman, 2010) proposes that temporal proximity alters the level of construal with which outcomes or events are represented. For instance, outcomes that are more proximal are represented more concretely, whereas events in the distant future are represented in more abstract terms. Differences in the level of abstraction lead to differential weight placed on decision alternatives (Malkoc, Zauberman, & Ulu, 2005). Accounts of temporal distance engendering greater uncertainty may also fall under the umbrella of representation, as greater uncertainty that future outcomes may not be delivered reflect weaker action-outcome contingencies.

Empirical support for this perceived-value perspective has been largely gleaned using DD-A procedures. For example, studies show that discount rates may be reduced by increasing the magnitude of delayed rewards available (Odum, Baumann, & Rimington, 2006), contextualising delayed rewards with episodic imagery (Peters & Büchel, 2010), providing explicit certainty of outcome delivery (Chapter 2) and reframing delayed rewards as potential losses (Mitchell & Wilson, 2010). Such findings favour an interpretation that time engenders factors, such as uncertainty, reduced saliency or affect, which change the way future outcomes are represented, or perceived, i.e. the discounting of future utility (Frederick, Loewenstein & O’Donoghue, 2002). The main point to emphasise however is that support for a perceived-value account is derived from discounting procedures that elicit estimates of subjective value, and therefore assume that time delays are perceived objectively. As such, adjusting-amount procedures may not fully reflect the impact that time delays have on subjective value (Fellows & Farah, 2005).

3.2.3 Perceived-time & time preference

In contrast to the perceived-value account, an alternative perspective actively adopts the view that humans do not in fact perceive future durations objectively (e.g. Roy, Christenfeld, & McKenzie, 2005; Zauberman, Kim, Malkoc, & Bettman, 2009). By taking this perspective, studies show that the degree to which such distorted perceptions of the future enter judgements or preferences depend on the way temporal information is presented. For example, future outcomes are rated as more preferable when presented as sequences of improving utility (Loewenstein & Prelec, 1993), and that the weight given to duration is dependent on the mode in which delays are evaluated, e.g. ratings, willingness to wait, and graded choices (Ariely & Loewenstein, 2000). The format of delay presentation has also been shown to be relevant when calculating discount rates. For example, despite describing equivalent temporal situations, consumers show greater discounting of outcomes when intervals are described as durations until receipt compared to descriptions based on dates of receipt (LeBoeuf, 2006; Read, et al., 2005), and show greater impatience when delaying the receipt of goods compared to expediting their arrival (Malkoc, et al., 2005; Weber, et al., 2007). Therefore, by considering the subjective nature of future time perception, discounting would appear to be sensitive to temporal dimensions of choice.

However, the critical point to emerge from a time-based view, is that discount rates are constructed for discrete choice scenarios, and thus not dependent on a discount curve over time. For example, in the studies above, a discount rate is computed for each choice or value assessment over successive time periods to show that discount rates at an initial time point t , are greater than those elicited by choices at a later time point, $t + 1$, in accordance with declining impatience, or hyperbolic discounting (Read, 2001). This is in contrast to the construction of discount rates elicited by psychophysical procedures mentioned previously, in which the discount rate reflects the general steepness of overall discounting, with the shape of the discount curve reflecting the hyperbolic nature.

In summary, different methodological strategies in calculating discount rates support alternative accounts of perceived value and perceived time as explanations for the discounting of future outcomes. We suggest these two accounts may be reconciled within a single DD framework, by exploiting the differences between DD-A and DD-T procedures, and thus address the extent to which DD procedures reflect individual's temporal orientations.

3.2.4 The current study

Given previous suggestions that adjusting-amount may not fully reflect the impact that time delays have on subjective value (Fellows & Farah, 2005), we sought to compare discounting behaviour under DD-A and DD-T by employing a fill-in-the blank method (FITB; Chapman, 1996). FITB requires participants to trade-off amounts (or time) in a given scenario (Smith & Hantula, 2008). Based on previous findings of distorted future time perception, and using a within-subjects design, we hypothesised that discounting rates to be steeper when elicited DD-T compared to DD-A procedures. To examine whether the two procedures relate to future temporal perspectives we measured individual's future orientation using the consideration of future consequences scale (CFC; Strathman, Gleicher, Boninger, & Edwards, 1994). Scores on the CFC reflect the importance a person assigns to immediate compared to delayed consequences analogous to the concept of time preference. For example, individuals scoring low on the CFC attach a higher degree of importance to immediate outcomes and show little regard for future outcomes. As such, we hypothesised that greater or reduced consideration of the future would be associated with shallower or steeper discounting respectively; however, we expected these associations to be more prominent under DD-T than DD-A procedures.

3.3 Method

3.3.1 Participants

Ninety participants (41 males, mean age 21.3 ± 3.3 , range 18 – 27 years) were recruited from the volunteer website of the University of Manchester (UK). All participants had normal or corrected-to-normal vision. To prevent any impact that familiarisation with the task or concept of delay discounting, participants were screened to ensure none were students of psychology or economics. All participants signed a consent form approved by the local ethics committee.

3.3.2 Procedure

Participants were provided with task instructions prior to completing two computerised DD tasks for hypothetical monetary rewards and the Consideration of Future Consequences Scale within a single laboratory session lasting approximately 30 minutes. Upon completion, participants were debriefed and reimbursed with £5.

3.3.3 Discounting Tasks

Assessment of discounting was made using the “fill-in-the blank” method described by Chapman, (1996). A small (£10) and large (£100) monetary amounts were used and, the order of tasks was counterbalanced across participants.

In the *Adjust-Amount DD Task (DD-A)*, participants were presented with the following scenario:

“You have won a lottery prize and are given a choice in how to receive your winnings. You can receive either £10 (*or* £100) in x time, or £_____ now. What is the minimum amount of money you would accept now instead of waiting x time for £10 (*or* £100)?”

Where x represented delays of 2 days, 30 days, 1 year, 2 years, 5 years and 10 years. Each delay/reward combination was presented twice, and the resulting 24 instances were delivered in random order.

In the *Adjust-Time DD Task (DD-T)*, participants were presented with the following scenario:

“You have won a lottery prize and are given a choice in how to receive your winnings. You can receive either £10 (*or* £100) in _____ days/weeks/months/years, or have £ x now. What is the maximum time you are willing to wait £10 (*or* £100) instead of accepting x amount now?”

Where x represented immediately available amounts: for small £10 trials, values of x were £9, £7.5, £5, £2.50, £1, £0.50; for large £100 trials, immediate amounts used were £95, £75, £50, £25, £15, £5. These amounts were based on median indifference points obtained from previous DD studies conducted in our lab. Each delay/reward combination was presented twice, and the resulting 24 instances were delivered in random order.

3.3.4 Consideration of Future Consequences (CFC; Strathman, et al., 1994).

The CFC is a 12-item scale reflecting an individual’s tendency to consider the immediate versus future consequences of their behaviour. Respondents rate the extent to which each item is characteristic of them along a 5-point Likert-type scale. Example items are “I often consider how things might be in the future and try to influence those things with my day to day behaviour”; “I only act to satisfy immediate concerns, figuring the future will take care of itself.” High scores reflect greater consideration of future consequences. The scale has high internal reliability ([alpha]s = .80, .82, .86 and .81, respectively in four college samples (Strathman et al., 1994, p 744. In the current sample, Cronbach’s alpha was .85.

3.3.5 Data Analysis

To estimate discounting and examine whether the form of discounting was consistent between the two tasks, group median and individual indifference points were fit with hyperbolic [$V = A / (1 + kd)$] and exponential [$V = Ae^{(-kd)}$] decay functions using non-linear regression (SPSS). V is the subjective value of the delayed outcome, A the amount to be discounted (here £10 or £100), d is delay period until A would be delivered, and k is a parameter describing the discounting rate. Higher values of k

indicate steeper discounting. Goodness of fit was determined by the degree of residual errors produced by the non-linear regression (for details refer to Chapter 2).

Distributions of k are known to violate assumptions of normality, therefore Wilcoxon Signed ranks test (non-parametric t-tests) were used to compare discount for small and large rewards, and adjust-amount and adjust-time tasks. All p values reported are Bonferroni corrected for multiple comparisons.

3.4 Results

3.4.1 Goodness of Fit

Figure 3.1 shows group median subjective values for amount as a function of delay (DD-A) and subjective values of time as a function of amount (DD-T) on the same graph to enable comparisons. As indicated, both procedures result in a discount curve that shows a reduction in subjective value over time. Whilst the discount curve produced by DD-T procedures appears much steeper relative to DD-A, discounting based on estimate of delay occurs over a much shorter time frame than that posed by DD-A procedures.

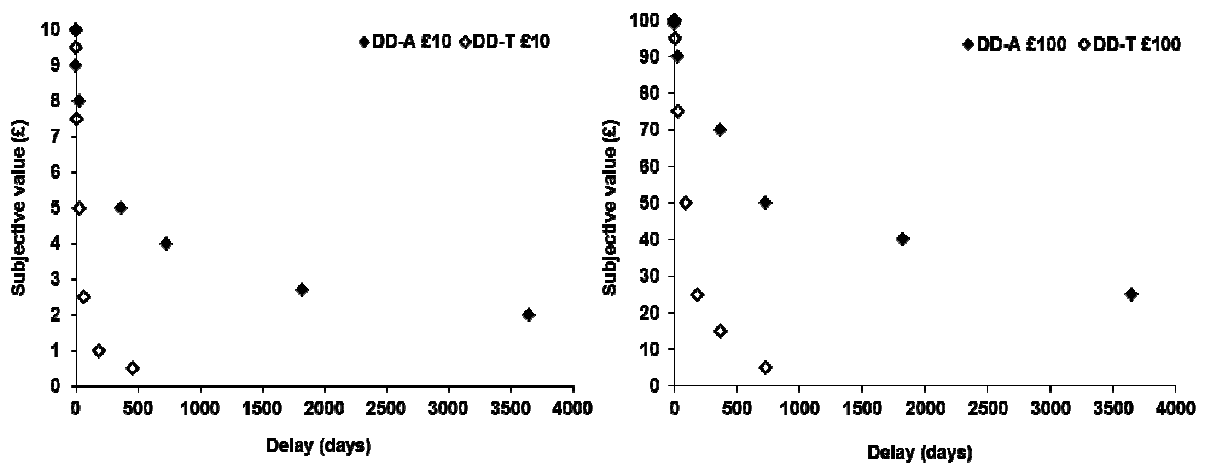


Figure 3.1. Group median estimates of reward amount and delay. Group median estimates of reward amount and delay elicited by DD-A and DD-T procedures for small (£10; left-panel) and large (£100; right-panel) reward.

Table 3.1 presents curve-fit summaries produced by fitting hyperbolic and exponential decay functions to group median indifference points. As indicated, a hyperbolic model provided a better approximation of data than an exponential model (indicated by greater residual errors for exponential function) for both reward amounts and tasks. As such, all further comparisons of k are derived from a hyperbolic function. Larger values of k for DD-T data indicate indicating steeper discounting compared with DD-A data.

Table 3.1. Discount k and associated goodness of fit measures (residual error) for hyperbolic and exponential fits to small and large rewards across task procedures.

Task	Amount	k	Residual error	R^2
DD-A	£10	0.0022	4.44	0.93
		(0.0012)	(11.81)	(0.81)
	£100	0.0011	148.43	0.97
		(0.00061)	(619.38)	(0.89)
DD-T	£10	0.041	0.60	0.99
		(0.024)	(1.98)	(0.98)
	£100	0.013	88.00	0.99
		(0.01)	(114.42)	(0.99)

Note: bracketed figures denote fit parameters according to an exponential model.

3.4.2 Task Procedure Comparisons

Individual participant data under both DD-A and DD-T procedures was fitted with a hyperbolic decay function. Analysis of reward amount effects revealed k values were significantly larger (i.e. steeper discounting) for smaller versus larger rewards under both DD-A, $z = -5.7$, $p < .001$, $r = .68$, and DD-T procedures, $z = -6.9$, $p < .001$, $r = .74$. Analysis of procedural effects revealed, k values were significantly larger under DD-T versus DD-A procedures for small ($z = -6.1$, $p < .001$, $r = .63$) and larger rewards ($z = -6.6$, $p < .001$, $r = .77$).

Table 3.2 presents Correlation coefficients between transformed discount k values and CFC scale scores. As indicated, CFC scores (indicative of greater weighting for future outcomes) showed a significant negative association with transformed k values under DD-T but not DD-A procedures; i.e. higher CFC scores were associated with smaller k values indicative of less discounting. Significant correlations also emerged between and within discount measures. Discount k parameters elicited under DD-A and DD-T were positively correlated indicating that individuals who discounted steeply under DD-A also discounted steeply under DD-T.

Table 3.2. *Bivariate correlations between consideration of future consequences scores and transformed k values*

	1	2	3	4	5
1. CFC					
2. DD-A £10	-.05				
3. DD-A £100	-.07	.78 **			
4. DD-T £10	-.33**	.51 **	.49 **		
5. DD-T £100	-.23 *	.49 **	.50 **	.86 **	

CFC: consideration of future consequences; **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 3.3 presents the results of linear regression analyses used to test if CFC scores significantly predicted the rate of discounting elicited by DD-A and DD-T tasks. As indicated, CFC scores significantly predicted discounting when discount rates were estimated using DD-T but DD-A tasks.

Table 3.3. *Summary of linear regression analysis predicting discount rate (log-transformed k values) from CFC scores*

	B	SE B	β
Constant	-2.32	.46	
DD-A £10 Lg k	-.005	.011	-.049
Note: $R^2 = .002$			
Constant	-2.62	.42	
DD-A £100 Lg k	-.006	.010	-.068
Note: $R^2 = .005$			
Constant	-.21	.41	
DD-T £10 Lg k	-.03	.010	-.33**
Note: $R^2 = .12$, ** $p < .01$			
Constant	-1.2	.38	
DD-T £100 Lg k	-.02	.009	-.24*
Note: $R^2 = .052$ * $p < .05$			

3.4 Discussion

The current study was concerned with the extent to which DD procedures for eliciting discount rates are reflective of individual's temporal orientations. This was assessed by comparing delay discounting behaviour produced by adjust amount (DD-A) and adjust delay (DD-T). Our results showed consistency with the majority of the literature in that the indifference points (IP) produced by DD-A and DD-T tasks were equally well described by a hyperbolic model and showed a magnitude effect, i.e., steeper discounting for smaller relative to larger rewards. Comparison between procedures revealed significantly higher k values (i.e. steeper discounting rate) for DD-T, although discounting rates from the two procedures positively correlated. Variation in CFC scores was significantly associated with discounting elicited under DD-T but not DD-A. Thus, whilst the procedural difference between DD-A and DD-T does not change the form of discounting, there are quantitative differences in the rate of discounting. Furthermore, DD procedures based on estimates of time not amount may be more sensitive to individual's future temporal perspective.

Because the predominant mode of assessment of DD in humans is DD-A, it is unclear if the two procedures provide equivalent assessments of discounting. Therefore, prior to assessing the extent to which DD procedures incorporate subjective estimates of delay, it was necessary to ascertain whether DD-T procedures provide a valid assessment of future reward discounting. Consistent with results from non-human animal (Green et al., 2007), both DD-A and DD-T were equally well described by Mazur's (1987) hyperbolic model. That is, the rate of decline in subjective value is steeper for more proximal time frames, and becomes shallower for more distal time frames. This suggests decreasing impatience is a feature of the choice context and not the choice procedures. This was supported by our observations of a magnitude effect and correlations between discounting elicited by both tasks. Previous studies based on DD-A procedures show that larger delayed rewards are discounted less steeply than smaller delayed rewards, i.e. the magnitude effect (e.g. Odum et al., 2006). If both DD-A and DD-T procedures reflect the same underlying discounting process, the same magnitude effect would be expected for DD-T procedures. Results show that this was indeed the case. Under both procedures, steeper discounting for smaller relative to large rewards and a strong positive correlation between discounting rates produced by DD-A and DD-T confirmed procedural differences did not affect the decision process *per se*. Regardless of the way in which IPs were elicited, participants behaved consistently.

Having established discounting based on estimates of delay (i.e. DD-T) our primary objective concerned the extent to which DD procedures reflect subjective temporal orientations. Consistent with our predictions based on previous findings of distorted future time perception (e.g. Zauberman et al., 2009), our data show that the rate of discounting was significantly steeper when based on the elicitation of estimates of delay as a function of reward amount (i.e. DD-T) than when based on the elicitation of reward amount as a function of delay (i.e. DD-A).

From a theoretical standpoint, explanations for underlying mechanisms that govern discounting fall in to two main categories which emphasise either perceived value or perceived time.

Perceived-value accounts propose that time delays engender factors which impact the representation, or perceived value of a delayed outcome, what can be considered as discounting of future utility (Frederick et al., 2002). Much of the evidence gleaned in support of this hypothesis has come from DD studies that calculate discount rates based on estimates of subjective values that render delayed outcomes subjectively equivalent, i.e. psychophysical DD-A procedures. In this way, the emphasis has been on manipulations to the way in which reward outcomes are presented which produce corresponding changes in discount rates.

Whilst informative towards understanding how variables engendered by time, such as uncertainty, or reward saliency are integral components of the discounting process, focusing on only reward outcome presentation overlooks the role of future time perception. Such an oversight may in part be due to the assumption that time delays presented under such contexts are perceived objectively. We attempted to remedy this by examining discount rates derived from estimates of delay as a function of reward amount in comparison to those based on estimates of amount as a function of delay. By doing so, our results show that whilst decreasing reward amounts were equated with corresponding increased estimates of time delay, contrary to the long time span employed by a DD-A procedure, individuals displayed considerably shorter time horizons.

This observation is in accordance with the view that individual's representations of the future are not only biased towards the present (Zauberman, et al., 2009), but are also susceptible to the way in which future time delays are presented (Ariely & Loewenstein, 2000; LeBoeuf & Shafir, 2009). Indeed, studies that have employed alternative strategies when calculating discount rates and focused on the framing of delay information show discounting is reduced when delays are reframed in terms of duration of time until receipt, as opposed to date of receipt (e.g. Read et al., 2005; LeBoeuf, 2006). Such reductions in discounting have been suggested to arise from processes of attention reallocation (Ebert & Prelec, 2007). Building upon the view that time information is typically underweighted within the decision context (Ariely & Loewenstein, 2000), by enhancing attention towards delay information individuals reconsider the impact of such durations within their evaluations (e.g. Read et al., 2005).

In the current study, we suggest that steeper discounting observed using DD-T procedures operated in the same manner. By requesting delay estimates that individuals would be willing to wait for a larger reward that would equate to receiving a smaller reward immediately, promoted a greater reconsideration of delay features within the choice, and thus revealed the impact of their temporal orientations.

Support for this interpretation can be gleaned by our observation of significant associations between participant's concern for future consequences and discount rates elicited under DD-T but not DD-A procedures. The relationship between high CFC scores and reduced discounting under DD-T is compatible with previous findings that show high CFC scores relate to delay of gratification (Strathman et al., 1994), future time orientation (Zimbardo & Boyd, 1999) and low impulsivity (Jaireman, Anderson, & Strathman, 2003). Therefore, we feel the current data show that by considering the manner in which discount rates are obtained, accounts of discounting based on perceived value and perceived time may be integrated within a common DD framework.

Methodologically, our results have implications for the association between self-report measures of impulsivity and delay discounting. The core assumption of DD is that outcome value is discounted as a function of the time delay until it is received, with steeper discounting reflecting a greater inability to wait for delayed rewards, i.e. impulsive choice. Despite associations between impulsivity and distortions in temporal perception (e.g. Wittman et al., 2007) correlations between self-report measures of impulsivity and delay discounting have proved inconsistent (for an overview see de Wit, et al., 2007). This may reflect that in human DD studies, the standard format for eliciting discount rates is based on the presentation of specified time delays, with the assumption that such delays are perceived "objectively", and reflect an individual's temporal horizon. However, as indicated in previous studies, and the current data, this is not the case.

It is worth noting that the current study employed a fill-in-the-blank (FITB) method. Whilst FITB procedures provide a valid assessment of DD behaviour, they have been suggested to require greater cognitive effort relative to standard adjustment procedures (Smith & Hantula, 2008). This however, could strengthen the argument that DD

procedures based on estimations of time duration reflect a more realistic impact of future time delays on subjective reward value, as they tap into individual's future temporal perspective (Ebert, 2001). Nevertheless, the current findings would benefit from future research that compared DD-A and DD-T using alternative adjustment/titration procedures. Further, given the use of adjustment DD tasks in other studies reported in this thesis, extrapolation of the results in the current study to those reported in other DD studies within this thesis cannot be assumed, and is therefore a limitation.

A second notable area for improvement concerns the use of reward amounts chosen in the DD-T task. Although reward amounts chosen were based on median indifference points obtained from previously conducted DD studies, it is possible that participants experience in DD-A and DD-T may have been quite different. As such, our paradigm would benefit from the employment of a yoked design, that derives estimates of subjective values under DD-A to inform the presentation of DD-T choices and vice-versa. In this way, the amounts and delays experienced under both tasks are more closely aligned.

3.5 Conclusion

Our findings show that discount rates derived from estimates of delay compared to estimates of reward value can account for subjective perceptions of the future, and demonstrate the compatibility of both perceived value and perceived time accounts of discounting within a common framework. Our results suggest that methodological features of DD tasks that draw attention towards dimensions of time may more reflective of individual's future orientation.

CHAPTER 4: Delay Discounting as Emotional Processing - an electrophysiological study

4. 1 Abstract

Both theoretical models and functional imaging studies implicate the involvement of emotions within the delay discounting process. However, defining this role has been difficult to establish with neuroimaging techniques given the automaticity of emotional responses. To address this, the current study examined electrophysiological correlates involved in the detection and evaluation of immediate and delayed monetary outcomes. Our results showed that modulation of both early and later ERP components previously associated with affective stimuli processing are sensitive to the signalling of delayed rewards. Together with behavioural reaction times that favoured immediacy, we demonstrated for the first time, that time delays modify the incentive value of monetary rewards via mechanisms of emotional bias and selective visual attention. Furthermore, our data are consistent with the hypothesis that delayed and thus intangible rewards are perceived less saliently, and rely on emotion as a common currency within decision making. This study provides a new approach to delay discounting and highlights a potential novel route in which delay discounting may be investigated.

4.2 Introduction

When faced with intertemporal trade-offs, both human and non-human animals behave myopically; that is, they prefer outcomes that are delivered sooner rather than later, even when the delayed outcomes provide the more optimal course of action. Such behavioural preferences can be accounted for by delay discounting (DD), the subjective devaluation of outcomes as a function of the delay until delivery. Under DD immediate outcomes are more valued and hold a greater motivational control over behaviour than delayed outcomes (Ainslie, 1975; Green & Myerson, 1993; Rachlin & Green, 1972). A number of explanations have been posited to account for delay discounting, for example, the uncertainty inherent in delayed outcomes, opportunity costs and reduced temporal horizons (for reviews see Berns, Laibson, & Loewenstein, 2007; Frederick, Loewenstein, & O'Donoghue, 2002; Green & Myerson, 2004). However, the consideration of the role played by emotional processes in DD has been relatively absent. This is striking, considering that decisions, particularly those about the future, involve predictions about future feeling (Idson, Liberman, & Higgins, 2004; Loewenstein & Schkade, 1999)

Here we build upon a theoretical framework that suggests because delayed outcomes are intangible, emotional processes are generated by evaluating future outcomes and serve as a guide for intertemporal choice. We extend this argument to suggest that DD arises from the reduced emotional salience of delayed outcomes, and as such DD reflects emotional processing.

Rewards, punishments and their respective magnitudes elicit affective states, or emotions, which govern motivated behaviour and action selection (Rolls, 1999). Given decision making involves the evaluation of potential outcome valence - rewards and punishments (e.g. Montague, King-Casas, & Cohen, 2006), emotions serve as an integral component of decision making (Bechara, Damasio, & Damasio, 2000; Lerner & Keltner, 2000; Schwarz, 2000). Indeed, in contrast to economic models of rational choice, such as expected utility theory (von Neuman & Morgenstern, 1944), there is accumulating evidence supporting the role of emotional processing within decisions involving uncertainty (Bechara, 2003; Heilman, Crişan, Houser, Miclea, & Miu, 2010;

Loewenstein, Weber, Hsee, & Welch, 2001; Quartz, 2009) and social interactions (Frith & Singer, 2008; Sanfey, 2007).

Following this perspective, and building upon the framework of emotion as a “common currency” for motivated behaviour and action selection (Montague & Berns, 2002; Rolls, 1999), Rick and Loewenstein (2008) hypothesised that the experience of emotion in the present can account for the apparent irrational behaviour during intertemporal choice. Central to their account is that future consequences are inherently ill-defined, or ‘intangible’. As such, the conscious experience of emotion in the present provides a proxy for encoding and evaluating these intangible outcomes. From this point of view, rather than an explicit trade-off between costs and benefits that occur at different time points, they suggest individuals chose between alternative courses of action based on competing immediately experienced emotions. On the one hand, emotional responses are elicited by outcomes occurring in the present. Given the inherent temporal and sensory proximity of present outcomes, such affective influences provide relatively intense emotional responses. In contrast, considering the prospect of future yet intangible consequences, elicits immediate anticipatory emotions that may be less intense (Lerner & Keltner, 2000). In this way, currently experienced emotions signal the value of potential future outcomes (Bechara, Damasio, Tranel, & Damasio, 1997), acting as informational inputs to the decision processes (Clore, Gasper, & Garvin, 2001; Clore & Huntsinger, 2007). Therefore, preferences for immediate over delayed outcomes, i.e. DD, can be understood as the emotional processing of less salient outcomes.

Consistent with this view, a number of behavioural studies have shown preferences for immediate over delayed rewards can be predicted by individual differences in affect tendencies (e.g. extraversion and neuroticism) and situational factors which enhance the experience of emotion (Augustine & Larsen, 2011; Hirsh, Guindon, Morisano, & Peterson, 2010; Hirsh, Morisano, & Peterson, 2008).

Similarly, neuroimaging studies of DD have demonstrated preferential recruitment of limbic regions (ventral striatum, amygdala, insula and orbitofrontal cortex) when choosing alternatives that confer immediate monetary rewards (Ballard & Knutson,

2009; Boettiger, et al., 2007; McClure, Ericson, Laibson, Loewenstein, & Cohen, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004). In addition, activity within the ventral striatum has been proposed to integrate parameters of reward magnitude and delay within a common signal that signifies reward saliency (Kable & Glimcher, 2007). More recently, exploring these mechanisms outside the confines of an explicit choice paradigm, greater activity within the anterior insula, a region implicated in affective signalling and the registration of emotions has been shown in response to immediately available, relative to preference matched delayed rewards (Luo, Ainslie, Pollini, Giragosian, & Monterosso, 2012).

However, enhanced reactivity in emotion-related circuitry for immediate compared to delayed rewards does not test Rick & Loewenstein's hypothesis that delayed outcomes are discounted *because* they are emotionally less salient. Modulation of event-related potentials (ERPs) based on the interaction between emotion and selective attention could provide a more explicit route to testing this hypothesis.

Experienced emotions guide selective attention in order to prioritize information of biological and motivational significance. Modulation of early ERP components involved in the detection of stimuli has been demonstrated when such stimuli carry affective content. For example, the amplitude of early components (< 250 ms), known to be sensitive to selective visual attention (Luck, Woodman, & Vogel, 2000; Mangun & Hillyard, 1991) are also modulated by affective or motivationally relevant stimuli (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Martin Eimer & Holmes, 2007; Kissler, Herbert, Winkler, & Junghofer, 2009; Sato, Kochiyama, Yoshikawa, & Matsumura, 2001; Schupp, et al., 2007). This evidence suggests affective stimuli capture attention automatically, aiding the detection of salient events, and the facilitation of adaptive behaviour (Brown, El-Dereby, & Blanchette, 2010; Schupp, et al., 2004; Schupp, Markus, Weike, & Hamm, 2003). Similarly, monetary rewards have been found to elicit early ERP modulations reflecting their role in guiding attentional process (Hickey, Chelazzi, & Theeuwes, 2010a) and is consistent with the view that monetary outcomes comprise affective value (e.g. Elliott, Newman, Longe, & Deakin, 2003).

In addition, longer latency components provide cognitive markers for outcome evaluative processes (Donchin, 1981). Of particular interest is a frontally distributed feedback-related negativity (fRN) that peaks 250-300 ms following the delivery of performance (correct/incorrect) or utilitarian (monetary win/loss) feedback (Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004). Based on observations that both outcome valence (reward/penalty) and affective responses (positive/negative) modulate the fRN amplitude (Hajcak, Holroyd, Moser, & Simons, 2005; Yeung, Holroyd, & Cohen, 2005; Yu, Luo, Ye, & Zhou, 2007), there is a growing consensus that the fRN reflects the motivational significance of outcomes even in the absence of explicit choice (Yeung, et al., 2005).

4.2.1 The current study

Building upon these results, we use ERP components as markers of emotion processing to examine the extent to which emotional processes drive the devaluation of future outcomes observed in delayed discounting. Following a non-explicit trade-off approach (Luo, et al., 2012) we address the hypothesis that delayed outcomes are perceived as less emotionally salient using a modified reaction-time task. This allows a distinction between phases of detection (early N1) and evaluation (fRN) of immediate and delayed monetary outcomes.

Firstly, we hypothesised that during detection phases, cues signalling potential delayed monetary outcomes would be perceived as less emotionally salient or ‘intangible’ relative to cues signalling more immediately available outcomes, and this would be observed as an attenuation of early sensory evoked ERPs (100-200 ms). Secondly, we hypothesised that during evaluative phases, feedback signalling delayed relative to immediate monetary outcomes would be evaluated as less emotionally favourable, observed as an enhancement of the later feedback related ERPs (> 300 ms).

4.3 Methods

4.3.1 Participants

Thirty-two non-psychology undergraduates (15 females, mean age 19.7 ± 1.4 , range 19-23 years) were recruited from the volunteer website of the University of Manchester. All participants were right-handed and had normal or corrected to normal vision, and were screened to ensure no current or previous neurological or psychiatric disorders. The study had local ethics approval and participants gave written informed consent after reading protocol instructions. Data from all 32 participants were subjected to statistical analysis.

4.3.2 Stimuli and Task

The study comprised a modified reaction-time task adapted for the purposes of delivering predictive cues and corresponding feedback signalling the delivery of rewards and penalties that would occur over three time points corresponding to now, one week and one month. These delays were chosen on the basis of previous piloting of the experimental paradigm. All stimuli and registration of response times were controlled using E-Prime software.

4.3.3 Behavioural Task

Figure 4.1 outlines the temporal sequence of events in a single trial. On each trial, participants were presented with one of the six predictive cues, presented centrally for 500 ms. The purpose of the cues was to signal the valence (reward/penalty) and ‘time pot’ (‘now’, ‘week’, ‘month’) of the impending outcome.

Predictive cues comprised a 3 cm x 3 cm square, and carried two dimensions of information regarding the utility of the trial outcome. Firstly, the background colour of the cues predicted a trial’s outcome valence (green for reward, red for penalty). These colours were chosen based on their previous use in studies using monetary gains and losses (e.g. Gehring & Willoughby, 2002; Wächter, Lungu, Liu, Willingham, & Ashe, 2009), and were not counterbalanced given their implicit and persistent associations with achievement situations (Anderson, Laurent, & Yantis, 2011; Moller, Elliot, & Maier, 2009).

Secondly, the image within the cues (i.e. hour glass, clock, and calendar) predicted the “time pot” of outcome delivery, either “now”, “one week” and “one month” respectively. It is worth noting here that the “now” time pot indexed the most immediately available time point of outcome delivery and was explained to reflect outcomes that would be received on the day of testing, i.e. after the experimental session (see Kable & Glimcher, 2010). Cue images were tested *a priori* to ensure they accurately represented the respective time pot, whilst remaining visually simple.

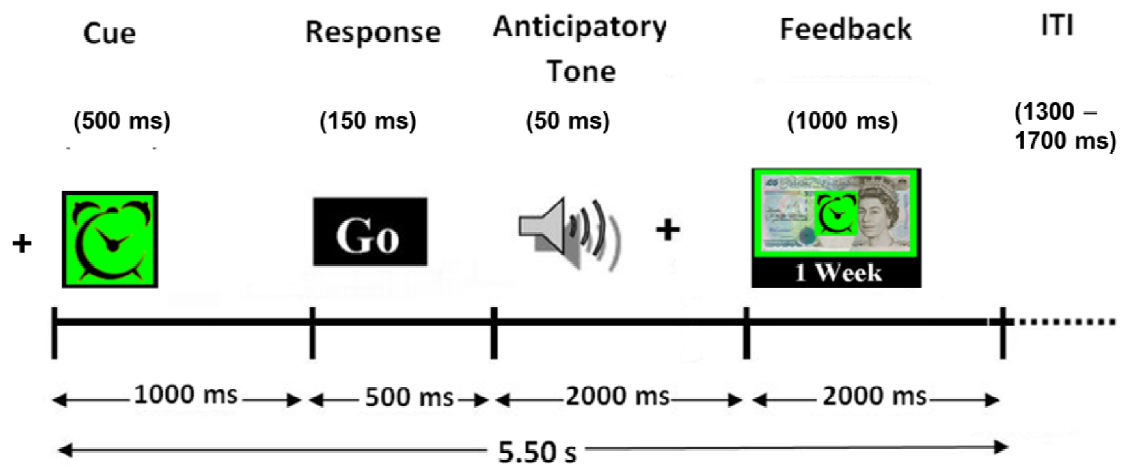


Figure 4.1. *Sequence of events within a single trial.* Trials commenced with a fixation followed by the presentation of a cue predicting subsequent monetary outcome valence and time pot (example shown here is for reward one week). Behavioural responses (left and right mouse buttons mapped to reward and penalty respectively and counterbalanced across blocks) are instructed by presentation of “GO”, followed by an anticipatory tone which signals the delivery of feedback (shown here for correct response as a reward delivered in one week).

Participants were informed the valence of cues corresponded with left and right mouse buttons (e.g. reward and penalty mapped to left and right respectively) and they were required to learn by trial and error which mouse button mapped to reward and penalty cues respectively (this would remain constant within a block but counterbalanced across

blocks of trials). 1000 ms after the onset of predictive cues, the word “Go” appeared briefly for 150 ms. This instructed participants to make their behavioural response, and avoided contamination of electrophysiological responses to predictive cues by behavioural action.

Participants were instructed their behavioural responses on each trial would subsequently receive monetary outcomes (gain 5 pence on reward trials, lose 5 pence on penalty trials) which would be either added to or deducted from the relevant time pot as predicted by the trial cue. Given the simplicity of the task and to maintain attention, participants were instructed that they could gain more than 5 pence on reward trials, and prevent losing more than 5 pence on loss trials if they responded quickly and accurately on respective trials, however, in reality speeded responses had no bearing on outcomes. They were also informed that failure to respond to the word “GO” within a 500 ms time window would be deemed as incorrect (and elicit “WRONG” feedback), and all incorrect responses would receive a 25 pence deduction across all time pots.

Following behavioural responses, the delivery of a 50 ms 500 Hz ‘anticipatory’ tone, with a corresponding fixation, signalled impending feedback which appeared centrally 2000 ms following tone offset. (The delivery of an auditory tone is part of a wider study aim to examine anticipatory responses, the results of which are not reported within the current paper).

Feedback stimuli for correct behavioural responses comprised an 8 cm x 3 cm rectangular image consisting of a £5 note (symbolising 5 pence) in which the trial’s predictive cue image was superimposed, and outlined in associated valence colour (Gregorios-Pippas, Tobler, & Schultz, 2009). In addition, the associated “time pot” was written beneath the image. Feedback for incorrect responses or those made outside a time window of 500 ms time window consisted of the word “WRONG” presented centrally. (In advance of the results, it is important to note that due to the low potential for incorrect responses made, responses towards “WRONG” feedback stimuli were not analysed).

The entire study comprised 6 blocks of 54 trials. To insure a degree of unpredictability in the likelihood of outcome delivery, and therefore, the occurrence of a feedback ERP (Hajcak, Moser, Holroyd, & Simons, 2007), within each block, two trials per delay time pot resulted in outcome omissions (22%), which comprised the words “NO-WIN” on reward trials and “NO-LOSS” on penalty trials presented at feedback. For statistical reasons omission feedback was not analysed, leaving 42 trials from each condition.

All feedback was displayed for 1000 ms and was followed by fixation for 1000 ms. The disappearance of fixation signalled the ending of a trial and was accompanied by a variable inter-trial interval jittered between 1300 – 1500 ms.

In between blocks, there was a short break in which participants were allowed to rest and the experimenter gave as motivation a fictitious update as to which time pot had accumulated the most earnings. This was in to ensure neurophysiological responses towards delayed outcomes reflected subjective value. Participants were lead to believe that on a trial by trial basis, monetary rewards and penalties from each trial would be accumulated within the three “time pots”. They were informed the goal of the experiment was to earn as much money as they could as their payment for taking part would reflect their behavioural performance, in that the “time pot” with the highest accumulated monetary gain over the course of the whole experimental session would be paid out to them. If the “now” time pot obtained the highest accumulated gains, they would be paid at the end of the experimental session. Conversely, if the “one week” or “one month” time pots showed the highest accumulated gains, they would receive payment after the stated delay. In reality, once the experimental session had ended, participants were debriefed as to the study’s true aims, and all participants received £10 for their participation. The experimental session lasted approximately ~ 1 – 1.5 hours.

4.3.4 EEG acquisition, processing and analysis

Event-related potentials were recorded using a Biosemi Active-Two amplifier system (Biosemi, Amsterdam, the Netherlands) from 64 active Ag/AgCl electrodes mounted in an elastic cap, according to the 10-20 system. Two additional electrodes, the common mode sense (CMS) active electrode and the driven right leg (DRL) passive electrode, were used as reference and ground electrodes, respectively (cf. <http://www.biosemi.com/faq/cms&drl.htm>). Vertical and horizontal electro-oculogram (EOG) was measured from electrodes attached to the outer canthus of each eye and from infra- and supra-orbital electrodes (of the left eye / of both eyes). Vertical and horizontal eye movement artefacts in the EEG were identified using a criterion of $\pm 100 \mu\text{V}$, and removed. All signals were sampled at a rate of 215 Hz using an on-line 0.2 Hz high-pass filter (forward phase shift). Brain Electrical Source Analysis 5.2 (BESA; Gräefeling, Germany) was used for data pre-processing and averaging.

Offline EEG analysis was conducted to generate ERPs time-locked to both predictive cue, and outcome feedback stimuli. Epochs were defined as -200 ms to 1000 ms relative to stimulus presentation. Baseline correction was performed based on the 200 ms pre-stimulus interval. ERPs of interest were calculated as the average over electrode clusters (see below), and filtered with a digital low-pass filter of 30 Hz (12dB/oct).

To examine emotional processes involved in the *detection* of delayed outcomes, we measured early sensory ERP responses (N1) towards predictive cue stimuli. To examine emotional processing involved in the *evaluation* of delayed outcomes we measured both early sensory (N1) and later cognitive (fRN) ERP responses towards correct feedback stimuli.

N1 was measured as the mean amplitude occurring 150-195 ms after both cue and feedback stimulus onset at a posterior electrode cluster (Oz, O1/O2, PO7/ PO8, P7/P8). fRN was defined as the mean amplitude occurring 250-300 ms after feedback stimulus onset over a fronto-central electrode cluster (Fz, F1/ F2, FCz, FC1/FC2, Cz).

Over the entire study (6 blocks of 54 trials) after excluding omission feedback data, the number of trials remaining for ERP averaging and subsequent analysis (42) were in line

with previous reports (Hajcak, Moser, Holroyd, & Simons, 2006; Luck, 2005). After rejecting trials due to excessive artefacts, the proportion of trials remaining for averaging in each condition ranged from 88.7 % - 93.7 %.

These data were submitted to repeated-measures analysis of variance, ANOVA with factors of valence (2 levels: reward, penalty) and delay (3 levels: “now”, “week”, “month”), with subsequent differences further explored using within subjects (paired) t-tests, Bonferroni corrected for multiple comparisons. Where appropriate, Greenhouse-Geisser adjusted degrees of freedom are reported.

4.4 Results

4.4.1 Behavioural data

Reaction times for trials on which incorrect responses were given (3.5% collapsed over all trial types) and which were faster than a threshold of 100 ms (4.8 %) were removed from analysis.

Figure 4.2 shows mean behavioural reaction times in response to predictive cues indicating the upcoming trial valence and outcome time pot. Participants responded significantly quicker following presentation of reward compared to penalty cues, $F_{(1,31)} = 8.7, p = .006, \eta_p^2 = .22$, and for immediate relative to delayed conditions, $F_{(2, 62)} = 25.1, p < .001, \eta_p^2 = .45$, with faster responses for now compared to “one wee” $t(31) = -3.4, p = .002$, and one month conditions $t(31) = -6.2, p < .001$, and faster responses for one week compared to one month conditions $t(31) = -3.5, p = .001$. Analysis also revealed a significant interaction between valence and delay, $F_{(2, 62)} = 4.7, p = .01, \eta_p^2 = .13$. As indicated in Figure 4.2, this interaction was driven by faster reaction times following reward now compared to reward one week, $t(31) = -4.6, p < .001$, and reward one month conditions, $t(31) = -5.5, p < .001$. Conversely, the effect of delay for penalty conditions only emerged between penalty now compared to penalty one month conditions, $t(31) = -2.9, p = .006$, Bonferroni corrected for multiple comparisons.

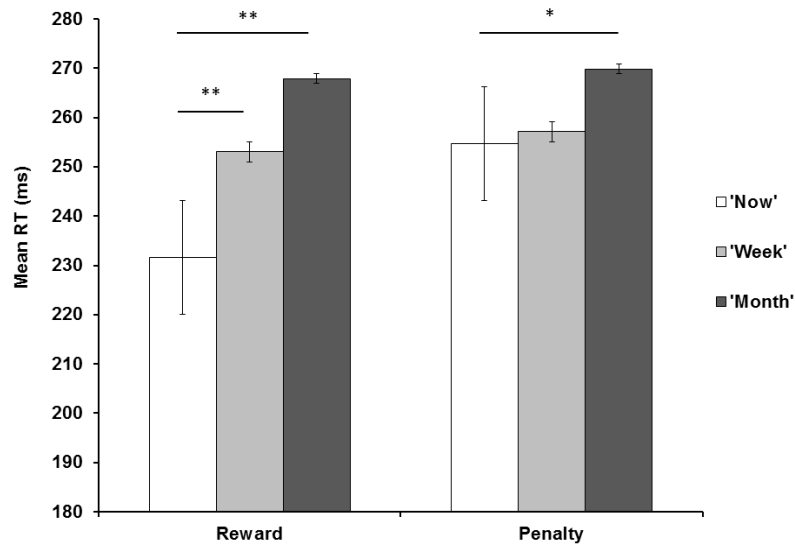


Figure 4.2. Mean reaction time (ms) in response to reward and penalty cues across delay conditions. Error bars indicate \pm one standard error. ** $p < .001$, * $p < .05$

4.4.2 Event-Related Potentials

4.4.2.1 Early detection of predictive cues

Within the N1 time window, no main effects of delay or valence emerged, however, visual inspection of grand averaged waveform revealed a negative deflection over temporal-occipital electrode sites within a later time window occurring 200-300 ms post cue onset. The latency and scalp distribution observed are more consistent with a selection negativity termed an early posterior negativity (EPN; Schupp, et al., 2003) and will be referred to as EPN from here on.

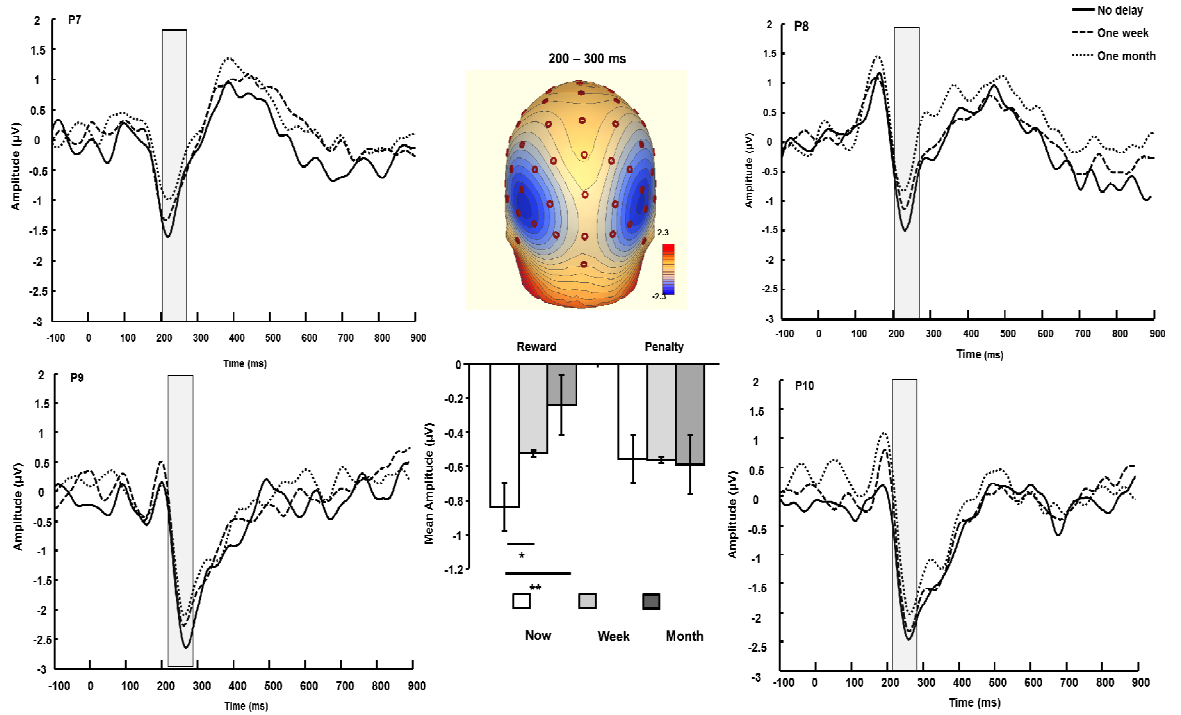


Figure 4.3. Cue evoked Grand averaged ERPs. Grand average ERP plots of reward cues at left (P10, P8), and right (P9, P7) hemisphere electrode sites, across delay conditions (now, week, month). Grey bar represents time window (200-300 ms) corresponding to scalp topography (top centre). Bar chart shows mean amplitude values from averaging over electrode cluster (P9/P10, P7/P8, P5/P6, PO7/PO8) for reward and penalty cues across delay conditions. Error bars indicate one standard error. * $p < .05$, ** $p < .001$.

After adjusting electrode cluster (P9/P10, P7/P8, P5/P6, PO7/PO8), EPN amplitudes showed a modulatory effect as a function of delay, $F_{(1.9, 58.6)} = 4.8$, $p = .01$, $\eta_p^2 = .12$. This delay effect was driven by larger EPN amplitudes elicited by cues signalling immediate compared with one month delayed outcomes $t_{(31)} = -3.0$, $p = .006$. There was no main effect of valence, however, a significant interaction between delay and valence emerged, $F_{(1.9, 58.6)} = 3.6$, $p = .03$, $\eta_p^2 = .20$. Reward cues now were significantly larger than reward cues signalling one week, $t_{(31)} = -2.6$, $p = .01$ and one month, $t_{(31)} = -5.4$, $p < .001$. After Bonferroni correction, reduced amplitudes for reward cues one month versus one week approached significance, $t_{(31)} = -2.0$, $p = .06$. Conversely, cues signalling penalties did not show changes in EPN amplitude (see Figure 4.3).

4.4.2.2 Early detection of feedback

The presentation of feedback stimuli elicited a negative deflection, with a mean peak latency of 172 ms, consistent with an occipital N1 component indexing selective visual attention. Mean N1 amplitudes showed a significant main effect of valence, $F_{(1, 31)} = 8.9$, $p = .005$, $\eta_p^2 = .22$, with more negative amplitudes following reward relative to penalty feedback. Mean N1 amplitudes also showed a main effects of delay, $F_{(1.7, 52.8)} = 16.9$, $p < .001$, $\eta_p^2 = .35$. As illustrated in Figure 4.4, this delay effect was driven by a linear reduction in mean N1 amplitude across delays, $F_{(1, 31)} = 24.7$, $p < .001$, with larger amplitudes elicited by feedback signalling immediate outcomes relative to one week, $t_{(31)} = -3.9$, $p < .001$, and one month delays, $t_{(31)} = -5.0$, $p < .001$, and for one week relative to one month, $t_{(31)} = -2.7$, $p = .011$. No interactions between delay and valence were observed.

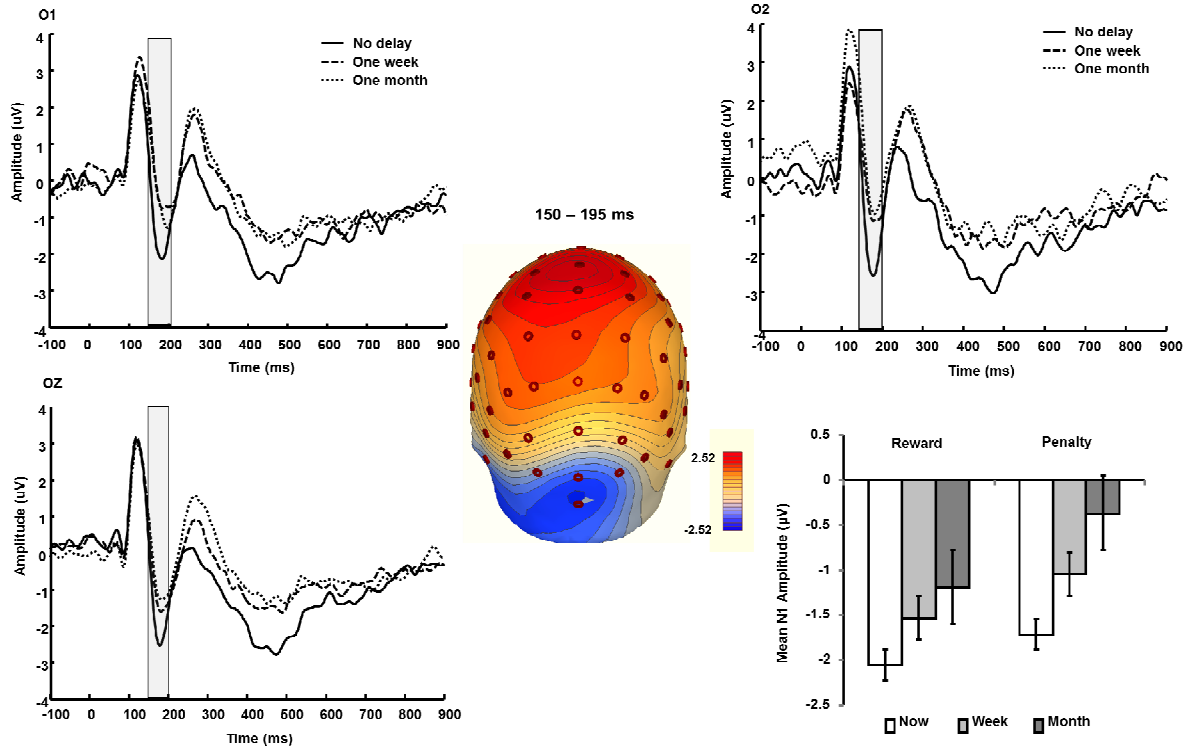


Figure 4.4. Grand averaged ERPs for early detection of feedback. Grand average ERP plots of reward feedback at left principal electrodes sites (O1,O2, Oz) across delay conditions (now, week, month). Grey bar represents time window (150 - 195 ms) corresponding to scalp topography (top centre). Mean amplitudes values from averaging over electrode cluster (POz, Oz, O1/O2, PO7/ PO8, P7/P8) for reward and penalty cues across delay conditions. Error bars indicate one standard error.

4.4.2.3 Evaluation of feedback

Figure 4.5 illustrates the negative N2-component between 250- 300 ms observed at fronto-central recording sites, consistent with feedback related negativity (fRN) topography and latency. fRN amplitudes showed a main effect of valence, $F_{(1, 31)} = 4.5$, $p = .04$, $\eta_p^2 = .13$, with larger negative deflections following penalty relative to reward feedback. There was also a main effect of delay, $F_{(2, 62)} = 42.7$, $p < .001$, $\eta_p^2 = .44$. Planned contrasts indicated this was driven by a significant linear trend, $F_{(1, 31)} = 36.3$, $p < .001$, with larger negative deflections elicited by both one week, $t_{(31)} = 3.8$, $p = .001$, and one month, $t_{(31)} = 6.0$, $p < .001$, relative to now conditions, and larger fRN

amplitudes in following one month relative to one week conditions $t_{(31)} = 4.0, p = .001$. Analysis further revealed a significant interaction between valence and delay, $F_{(2, 62)} = 3.9, p = .03, \eta_p^2 = .11$. Post-hoc comparisons revealed a differential effect of delay on fRN amplitudes with respect to valence; with larger fRN deflections following one week, $t_{(31)} = 3.9, p < .001$ and one month, $t_{(31)} = 7.4, p < .001$ relative to now reward conditions. After Bonferroni correction ($\alpha = .008$), relative to penalty now conditions, only increasingly negative fRN amplitudes for one month penalty feedback, $t_{(31)} = 2.9, p = .007$, reached significance.

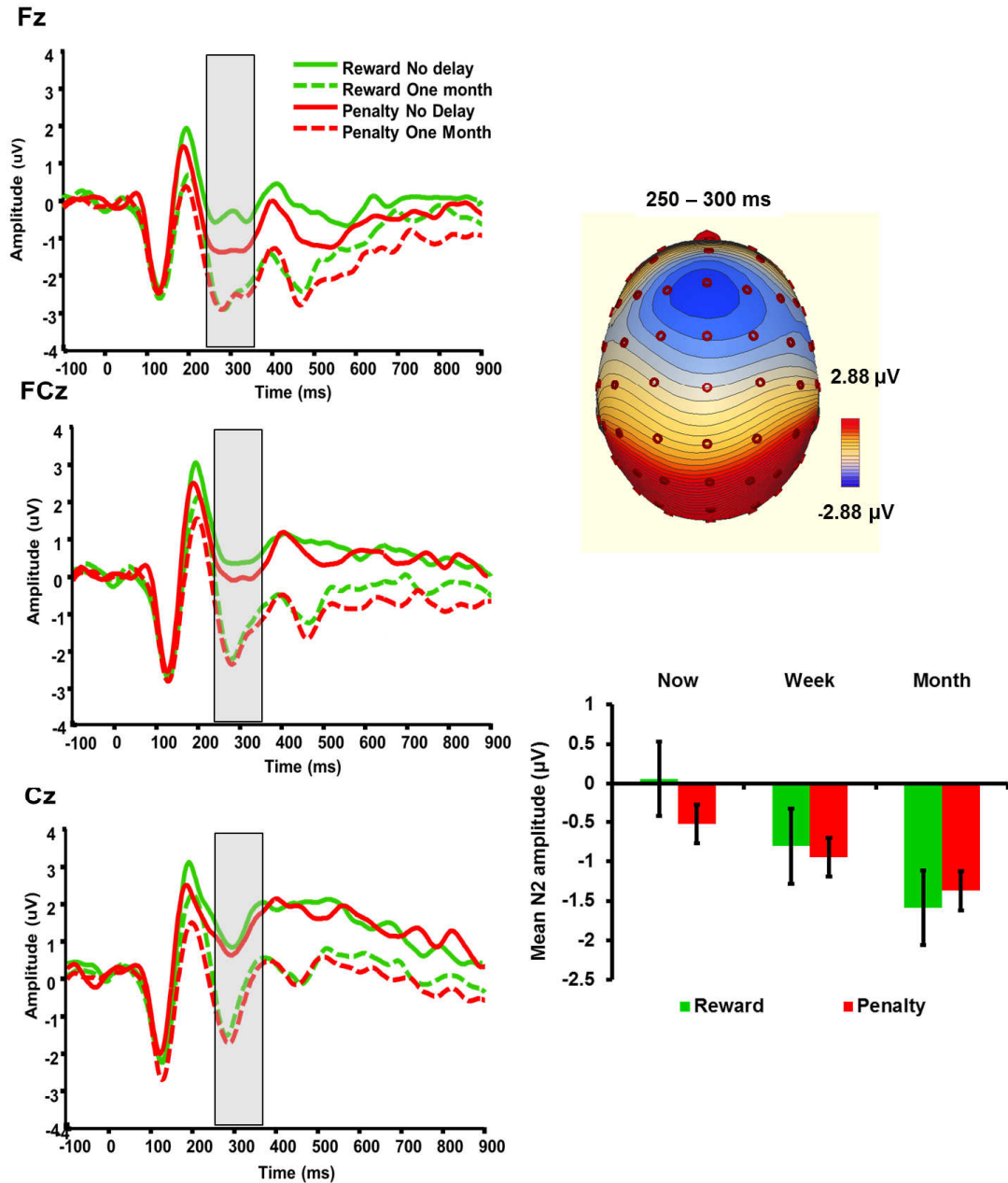


Figure 4.5. Grand averaged ERPs for feedback evaluation. Grand average ERP plots of reward feedback at principal fronto-central electrodes sites (Fz, FCz, Cz) across delay conditions (now, week, month). Grey bar represents time window (250-300 ms) corresponding to scalp topography (top right). Mean amplitudes values from averaging over electrode cluster (Fz, F1/F2, FCz, FC1/FC2, Cz, C1/C2) for reward and penalty cues across delay conditions. Valence x delay interaction for fRN amplitudes at FZ electrode; Error bars indicate one standard error.

4.5 Discussion

Taking a novel approach, the current study explored the role of emotion in delayed outcome processing by examining electrophysiological markers previously associated with the detection and evaluation of affective stimuli. Our main findings reveal time delays modify the incentive value of monetary rewards via mechanisms of emotional bias and selective attention. Both early (N1 and EPN) and later (fRN) ERP components demonstrated a sensitivity to temporal features of carried by stimuli associated with the delivery of delayed rewards. Furthermore, electrophysiological responses were paralleled by modified behavioural reaction times that favoured immediacy. Our findings are consistent with the hypothesis that future rewards are devalued as a function of delay because they are less emotionally salient (Rick & Loewenstein, 2008) and highlight a potential novel route in which delay discounting may be investigated.

In contrast to previous studies of delay discounting, we employed a modified reaction time task to allow examination of electrophysiological correlates involved in the detection and evaluation of delay-associated stimuli.

In terms of detection, we had hypothesised that cues predicting delayed outcomes would attenuate early latency N1 amplitudes relative to cues predicting more immediate and thus more salient outcomes. Contrary to our expectations, no modulation of N1 was detected. Instead, we observed a negative deflection over the same temporo-occipital electrode sites occurring between 200-300 ms. This latency and topography are more consistent with descriptions of an early posterior negativity (EPN; Schupp et al., 2003).

Unlike N1 which is primarily associated with visual spatial attention, the EPN is thought to reflect the selection of visual target features that require more elaborate processing (Codispoti, Ferrari, & Bradley, 2006). One such feature is emotional content. Enhanced EPN amplitudes have been reported across a range of visual stimuli (pleasant and unpleasant versus neutral) including affective pictures (Carretié, et al., 2004; Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Schupp, Junghofer, Weike, & Hamm, 2003; Schupp, Flaisch, Stockburger, & Junghöfer, 2006; Schupp, et al., 2007), emotional semantic content (Kissler, et al., 2009; Schacht & Sommer, 2009; Scott,

O'Donnell, Leuthold, & Sereno, 2009) and emotive facial expression (Eimer, Holmes, & McGlone, 2003; Sato, et al., 2001). This early selective processing within the visual cortex reflects the higher premium placed on stimuli that are either explicitly task relevant, or hold intrinsic emotional significance (Schupp, et al., 2003). Although unexpected, our observation of an EPN is of particular relevance to an emotional based account of delay discounting. Enhanced EPN responses following cues predicting immediate relative to delayed rewards suggests the detection of temporal aspects associated with reward involves the rapid registration of emotional significance imparted by time delays on reward value. The lack of any delay modulation for penalty cues is of equal interest given the similar gain-loss asymmetry observed within behavioural delay discounting studies (Green & Myerson, 2004), and neural dissociations between reward and penalty valuation (e.g. Delgado, et al., 2003)

ERP responses indicating enhanced attention capture by immediacy were paralleled by behavioural reaction times. Consistent with previous studies of incentive motivation we found faster behavioural reaction times for reward relative to penalty cues (Mir, et al., 2011). Furthermore, despite the redundancy of delay information for behavioural action, quicker reaction times followed cues signalling immediate relative to delayed outcomes.

We also examined early visual processing in response to the delivery of feedback for behavioural performance. Employing explicit indicators of monetary outcomes (c.f. Gregorios-Pippas et al., 2009) we observed enhanced N1 amplitudes following the presentation of reward relative to penalty feedback, and immediate as compared to delayed feedback. Previous studies report both attended stimuli (Hillyard & Anllo-Vento, 1998; Hillyard, Vogel, & Luck, 1998) and stimulus features which carry motivational relevance (Foti, Hajcak, & Dien, 2009; Gable & Harmon-Jones, 2011; Keil, et al., 2002; Potts, Patel, & Azzam, 2004) enhance the magnitude of the N1 response. Building upon these observations, the current data would suggest amplification in the perceptual encoding of reward and immediacy features within feedback stimuli (e.g. Hillyard, Vogel et al., 1998).

In terms of later cognitive evaluation of monetary feedback, we observed delay-related modulation of a fronto-central negative deflection occurring around 300 ms post feedback onset, consistent with previous reports of an fRN (Hajcak, Holroyd, Moser, & Simons, 2005; Holroyd & Coles, 2002; Nieuwenhuis, et al., 2004). The fRN component is thought to reflect activity of an evaluative system that assigns motivational relevance to outcomes (Gerhing & Willoughby, 2002) along a ‘good-bad’ dimension (Hajcak, et al., 2006). Larger fRN responses following the delivery negative valence or low magnitude outcomes signal feedback is less favourable and inconsistent with expectations (Pfabigan, Alexopoulos, Bauer, & Sailer, 2010; Wu & Zhou, 2009; Yeung, et al., 2005). Considering this, our observation of an enhanced fRN response towards delayed feedback would imply delays are perceived as unfavourable and may reflect the reduction in outcome magnitude as a function of time; that is, delay discounting.

At this point two possible interpretations can be raised to explain the current findings as a whole. On the one hand, evaluating delayed rewards as unfavourable may have biased the allocation of visual attention towards cues predicting immediate outcomes. Previous studies have provided converging evidence to suggest the incentive value of rewards enhances visual attention (Della Libera & Chelazzi, 2009; Engelmann, Damaraju, Padmala, & Pessoa, 2009; Small, et al., 2005; Weil, et al., 2010). However, it is critical to note that these previous studies focus on the role of reward in guiding *endogenous* attention. As such, participants were voluntarily able to utilise monetary feedback to inform their subsequent behavioural responses. In contrast, participants within the current study did not have any control over the value of outcome feedback, nor were they able to utilise feedback for subsequent behavioural performance. The inconsequential effects of delay information therefore, reflect the automatic nature characteristic of *exogenous* attention. This is worth considering given differential effects of temporal aspects of processing between exogenous and endogenous attention (for review see Carrasco, 2011).

An alternative interpretation is that the evaluation of feedback may have been facilitated by mechanisms of selective attention established at cue detection stages. According to cognitive studies of selective visual attention, the reallocation of attention resources towards emotional or task relevant stimuli influences later stages of cognitive

processing (Schupp, et al., 2007; Zeelenberg, Wagenmakers, & Rotteveel, 2006). From this perspective, emotion facilitated attention capture offered by predictive cues primed areas of the visual system to detect and attend to the more relevant features within outcome feedback, namely, immediacy (Vuilleumier, 2005). The correspondence between behavioural reaction times and EPN but not fRN responses, despite the redundancy of delay information is consistent with this perspective. The implication that emotional salience of immediate monetary reward biases motivational value is also consistent with fRN literature. The assigning of motivation relevance to outcomes, that is, what constitutes a ‘good outcome’, is highly dependent on the saliency of task stimuli used (Moser & Simons, 2009; Nieuwenhuis, et al., 2004). This interpretation is more consistent with the notion that delayed rewards are ‘intangible’ and that emotional proxies may guide intertemporal decisions (Rick & Loewenstein, 2008). Similarly, such an account would offer potential insights to observed framing and contextual effects within delay discounting studies (e.g. Peters & Büchel, 2010).

Whilst both interpretations have equal merit, and rest upon substantial evidence, it is important to address several points. Firstly, the EPN component has not previously been explored in relation to visual stimuli that predict monetary incentives, and therefore it is unclear whether visual stimuli associated with monetary rewards hold emotional significance *per se*. Similarly, our elicitation of an fRN differs in methodology with previous feedback related studies. Finally, our aim here was primarily to establish the role for emotional processing within the context of delayed discounting, and not imply causal mechanisms. Suffice to say, we feel the current findings demonstrate both early and later components of cortical processing are sensitive to temporal features of reward-related stimuli outside the confines of explicit choice, and demonstrate the impact that delay information has on the affective quality of monetary outcomes. Whether sensitivity towards an outcome’s temporal dimension is orchestrated by higher order evaluative networks, visual sensory systems or an interaction between the two remains to be seen (Raymond, 2009). Given the novel measurement of both EPN and fRN components within the current study, the issues outlined would benefit from further investigation.

Further investigation may also be warranted based on two relevant issues that the current study did not explicitly address. Firstly, although the current study focused on emotional processing within the context of delay on monetary outcomes, given the reward network is activated by both primary and secondary rewards (Kim, Shimojo, & O'Doherty, 2011), the consistency in neural activation in response to delayed monetary and juice rewards (McClure, et al., 2007) and findings showing selective visual attention is captured by affective (pleasant/unpleasant) content, monetary and food stimuli (Hickey, et al., 2010a; Nummenmaa, Hietanen, Calvo, & Hyönä, 2011), we suggest our findings should be equally as generalisable. Furthermore, given the affective quality under investigation, and previous studies that show steeper discounting for consumable rewards (Estle, Green, Myerson, & Holt, 2007; Odum & Rainaud, 2003), we would predict that alternative rewards like food rewards may show enhanced neural differences between now and delayed outcomes.

Secondly, whilst we did not consider individual differences in personality, emotional/reward responsiveness or states within the current study, there is no doubt they play a key role in motivational tendencies that underlie approach-avoid behaviours. Given the relationship between DD and individual differences in motivational variables (e.g. extraversion and neuroticism), via the use of affect-regulating strategies (Augustine & Larsen, 2011; Hirsh, et al., 2010), examining the relationship between such variables and neural responses towards delayed outcomes as indexed by the current study would be an area of future investigation. Indeed, recent findings have shown greater differentiation between delayed and immediate outcomes in the N1 and fRN in individuals prone to hypomania, in addition to elevated N1 amplitudes to rewards per se (Mason, O'Sullivan, Blackburn, Bentall, & El-Deredy, *in press*).

Nevertheless, despite its limitations and caveats, this study, to our knowledge is the first to examine the modulating effects of outcome delays using electrophysiological techniques. In doing so, we feel that the current study highlights a potential novel route in which delay discounting may be investigated. Furthermore, our data is in accord with recent neuroimaging attempts that highlight the influential role of attention and reward saliency within delay discounting processes (e.g. Peters & Büchel, 2010).

4.6 Conclusions

To conclude, our novel approach provides evidence that the detection and evaluation of delayed monetary rewards consists of a rapid registration of the significance delays impart. The attenuation of early indices of selective visual attention, and later cognitive evaluation suggest an immediacy bias towards reward saliency, or '*tangibility*' that is emotional in origin. These findings are consistent with the theoretical position that delayed and thus intangible outcomes are perceived less saliently, and support the notion of emotion as a common currency within decision making (Rolls, 1999).

CHAPTER 5: ‘*If*’ and ‘*What*’ Rewards Dissociate Risky and Impulsive Choices

5.1 Abstract

Most decisions involve some type of uncertainty, for example, ‘*if*’ an outcome will occur, i.e., uncertainty in outcome likelihood, or ‘*what*’ an outcome will consist of i.e. uncertainty in outcome utility. However, it is unclear whether ‘*if*’ and ‘*what*’ uncertainties reflect distinct decision processes.

Across two behavioural experiments and using a novel paradigm we demonstrate this distinction. Findings from Experiment 1 revealed preferences for rewards that are uncertain in outcome occurrence (UnO) and utility (UnU) are uniquely associated with individual differences in BAS subscales of drive and fun-seeking respectively. Findings from Experiment 2 revealed preferences for UnO and UnU uniquely predict Iowa Gambling Task and Delay Discounting performance respectively.

Collectively, our results suggest uncertainty in outcome utility impacts the ability to represent and predict outcomes. This is a defining feature which differentiates between uncertainties in outcome likelihood and utility and is moderated by variation in BAS sensitivities. Furthermore, our results provide a potential mechanism for distinguishing between risky and impulsive choice.

5.2 Introduction

Decision making involves responding to and choosing between outcomes that are uncertain (Behrens, Woolrich, Walton, & Rushworth, 2007). According to Reinforcement Sensitivity Theory, two motivational systems, behavioural approach and inhibition (BAS/BIS) govern responses towards cues that signal rewards and penalties, respectively (Gray, 1990). Carver & White's (1994) self-report BIS/BAS scales are the most widely employed measure that captures individual variation within these two motivationally relevant dimensions. Their application within real world contexts have consistently shown sub-components of both BAS drive and fun-seeking relate to 'risky' lifestyle choices such as drug use, binge drinking and smoking (Egan, Kambouropoulos, & Staiger, 2010; Voigt, et al., 2009; Zisseron & Palfai, 2007), whereas engaging in explicitly risky behaviour such as gambling can be located in BAS drive sensitivity (O'Connor, Stewart, & Watt, 2009). Alternatively, BAS reward-responsiveness conveys a protective quality against risky decision making (Voigt, Dillard, Braddock et al., 2009). These findings suggest the distinct aspects of reward availability may play a role in responding to decision uncertainty (Bjork, Smith, & Hommer, 2008; Depue & Collins, 1999).

However, quantifying BIS/BAS associations within an economic framework of decision making has proved inconsistent. For instance, a number of studies report positive associations between BAS reactivity and risky decision making (Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2006; Kim & Lee, 2011; Suhr & Tsanadis, 2007; van Honk, Hermans, Putman, Montagne, & Schutter, 2002). However, in some cases, risky choice has also been linked with low levels of BAS sensitivity (Franken & Muris, 2005) or higher BIS (Demaree, DeDonno, Burns, & Erik Everhart, 2008). Alternatively, others have found no contribution of BIS/BAS tendencies to decision making (Brand & Altstötter-Gleich, 2008; Danner, Ouweland, van Haastert, Hornsveld, & de Ridder, 2012).

Given the complexity of laboratory decision tasks, such inconsistencies may be attributable to confounds regarding the type of decision uncertainty presented (Brand, Recknor, Grabenhorst, & Bechara, 2007; Buelow & Suhr, 2009). As such, a closer

examination of individual differences in decision making suggests a need to distinguish types of uncertainty (Ferguson, Heckman, & Corr, 2011).

In the current study, we address this by distinguishing between two types of uncertainty based on economic parameters of choice: uncertainty created by outcome probability and uncertainty created within outcome utility. We first describe current conceptions of uncertainty within decision research, and then identify uncertainty within utility as a neglected source of decision uncertainty. Finally, we outline a novel paradigm which addresses this potential distinction between outcome probability and utility in relation to variation in subscales of the BAS.

5.2.1 Economic Parameters of Decision Making Under Uncertainty

Expected Utility Theory (EUT; von Neumann & Morgenstern, 1944), is the most prominent model describing how decisions under contexts of uncertainty *should* be made to maximise reward. Key parameters that constitute choice are the desirability or ‘utility’ of an outcome (often quantified by outcome amount) and the likelihood of an outcome occurring (probability of an outcome), which collectively give rise to an outcome’s expected utility. Accordingly, decisions are determined by alternatives which offer the greatest expected utility.

Two important features of EUT are the formalisation of uncertainty along the single dimension of outcome probability (Kahneman & Tversky, 1982), and a distinction between known (risk) and unknown (ambiguity) outcome probabilities (Ellsberg, 1961; von Neumann & Morgenstern, 1944).

These conceptions are meaningful where such numerical information can be made available, for example, within financial decision making domains. However, in the majority of situations, outcomes are rarely specified in such discrete terms; rather, outcomes that tend to be less concrete in their numerical representation (Huettel, 2010; Rick & Loewenstein, 2008). Considering this, we suggest that a distinction can be made between uncertainty about ‘*if*’ outcomes will occur (i.e. uncertainty created by probabilities), and an uncertainty about ‘*what*’ outcome will consist of (i.e. uncertainty created within utility). Theoretically, these types of uncertainty may represent

dissociable operations based on how they affect outcome representations, expectations and ultimately choice.

Given the fundamental responsibility of the BAS system lies in the initiation of reward-seeking behaviour, differences between high and low BAS tendencies may determine sensitivities towards reward that are uncertain in terms of ‘*if*’ and ‘*what*’. We propose this may be demonstrated by aligning uncertainties about ‘*if*’ and ‘*what*’ with economic parameters of outcome likelihood and outcome utility respectively and examining trait reward sensitivities (c.f.Ferguson, et al., 2011).

5.2.2 *‘If’ as Uncertainty in Outcome Occurrence*

In contrast to the normative stance predicted by the EU model, human choice is highly susceptible to probability. Empirical evidence has shown that individuals are predominantly risk-averse when choices are between certain and defined probabilistic alternatives (Kahneman & Tversky, 1979). Conversely, when choices are between risky and ambiguous alternatives, individuals demonstrate a shift towards risk-seeking, preferring defined probabilistic alternatives to those that lack information regarding outcome likelihood (Curley, et al., 1986; Einhorn & Hogarth, 1986).

Whether probabilistic information is stated, (as in descriptive choice) or inferred (as in experiential choice), the critical implication of such studies suggests that a decision maker is able to build a representation about the likelihood of an outcome occurring based on some form of objective knowledge (Frisch & Baron, 1988). Therefore where uncertainty lies in predicting ‘*if*’ an outcome will occur or not, what shapes preference is the strength and confidence of such representations.

5.2.3 *‘What’ as Uncertainty in Utility*

As previously noted, within decision making literature, the concept of uncertainty has been limited to the distinction between known and unknown outcome likelihoods (Huettel, 2010). Nevertheless, there are several observations which suggest uncertainty in ‘*what*’ may be a valid source of uncertainty within choice.

In the application of economic models to animal foraging behaviour, a distinction is made between uncertainty created by variability's in delays and amounts (Kacelnik & Bateson, 1996). Variable delay and amount parameters exert different behavioural responses within animals, and are therefore treated as distinct sources of uncertainty (Gil & De Marco, 2009; Kacelnik & Bateson, 1996; Matsushima, Kawamori, & Bem-Sojka, 2008). That animals tend to avoid food sources that are variable in terms of reward amount (equivalent to utility), has been considered a function of the ability to form future reward expectations (Gil & De Marco, 2009).

Varying reward utility has not been explicitly addressed within the human choice literature. However, it has been shown elsewhere that predicting *what* reward to expect is critical to processes of outcome evaluation and subsequent decision making (Bellebaum, Polezzi, & Daum, 2010). Similarly, the unpredictability of *what* reward will materialise has been considered to be potentially influential in sustaining heightened gambling behaviour, separate from the consideration of predictable outcomes themselves (Petry, 2005).

Indeed, unlike '*if*' where some form of representation can be achieved, a vagueness regarding outcome representation notably hinders the formation of outcome expectancies (Frisch & Baron, 1988). In this way, uncertainty about '*what*' outcome will occur, may lead to unstable or inaccurate representations about *what* to expect.

To summarise, whilst motivational approach tendencies have been associated with risky health choices, the relationship between BAS measures and decision uncertainty is unclear. This may reflect dominant conceptions of decision uncertainty along the single dimension of outcome likelihood. However, this view is not representative of uncertainty in everyday decisions, as decision outcomes often vary in terms of *what* they consist of, i.e. outcome utility. Very little is known about uncertainty in reward outcome utility within human choice literature, and therefore '*if*' and '*what*' uncertainties may provide an important distinction.

We address this issue by mapping ‘*if*’ and ‘*what*’ aspects of reward to economic parameters of probability and utility, and suggest their distinction resides in the construction of outcome expectancies.

5.2.4 The Current Study

The current study features two experiments that examine the potential distinction between outcome likelihood and utility uncertainty. Experiment 1 investigates whether creating uncertainty in outcome utility reflects a type of decision uncertainty that can be distinguished from uncertainty in outcome likelihood. We examine and compare behavioural preferences for rewards under different choice contexts and relate these preferences to variation in BAS sensitivity. Experiment 2 extends our methodology to examine whether behavioural preferences towards uncertainty in outcome likelihood and utility are predictive of behavioural performance on complex decision making tasks.

5.3 Experiment 1: Establishing a behavioural paradigm for ‘*if*’ and ‘*what*’

Experiment 1 sought to establish whether uncertainty in outcome likelihood and uncertainty in outcome utility reflect distinguishable sources of uncertainty. To achieve this, we examined behavioural preferences for rewards that were uncertain in their outcome occurrence and utility under different choice contexts (forced and free choice) and their relationships with behavioural approach sensitivities (as measured by Carver & White’s BAS scales) with two questions in mind: 1) do different types of uncertainty map to different components of the BAS? 2) Do individual’s preferences for different uncertainties vary across different choice contexts?

Our hypotheses were driven by the notion that ‘*if*’ and ‘*what*’ affect abilities to form outcome expectations. Therefore, based on previous studies and conceptions of BAS Drive and Fun, we hypothesised a positive relationship between drive and fun scores and preferences for rewards uncertain in outcome probability. Conversely, because uncertainty in utility may hinder outcome representations, we hypothesised a negative relationship between measures of BAS fun-seeking and drive and preferences for rewards uncertain in utility.

5.3.1 Methods

5.3.1.1 Participants

A sample of 84 (non-psychology/economics) students from University of Manchester (37 males) with mean age 22 ± 4.7 years were recruited through an internal volunteer website on an opportunity basis, and were reimbursed upon study completion with £5. All participants had normal or corrected-to-normal vision, and were screened to ensure no history or current involvement in gambling behaviours.

5.3.1.2 Monetary Reward Game Stimuli

Participants played a computerised monetary reward game programmed using E-Prime (PST Inc, Sharpsburg USA). Three green geometric shapes (circle, square and triangle) which formed the game cards were presented on a black background, instructions and response outcomes were typed in white. Each card was associated with a probability of winning (outcome) with a range of reward points (utility) in three conditions: Safe, Uncertainty in Outcome likelihood (UnO), Uncertainty in Utility (UnU) (Table 5.1).

The range of possible outcome values for the UnU condition reported in Table 5.1 were chosen on the basis of several pilot studies conducted. In these studies, the primary motivation was to create a variable distribution that would present a challenge for predicting the utility of an outcome. Given the experiential nature of the task (as opposed to descriptive choice), it was reasoned that acquisition of probability and utility information would rely on executive process of working memory (WM) capacity (see Rakow, Newell & Zougkou, 2009; Hertwig et al., 2004). Therefore, the range of values chosen for the UnU condition should i) challenge working memory capacity, ii) reflect a distribution such that no one specific value appeared explicitly more salient than the rest. An account of working memory popularised by Miller (1956), is that the amount of information that can be held in WM at any one time is about seven \pm two. Although more recent views have suggested a lower limit, these remains controversial (see Cowan 2010). Therefore, when constructing a distribution for UnU, we chose nine possible outcome values to reflect the possible maximum load for WM capacity.

Table 5.1. Choice options and associated probability/utility contingencies.

Condition	Probability of Win (%)	Utility of Win/No win (points)	Expected Value
Safe	90	45 / 0	40.5
UnO	50	101 / 0	50.5
UnU	90	3, 7, 11, 27, 40, 66, 73, 84, 99 / 0	41

UnO: Uncertainty in outcome occurrence; UnU: uncertainty in Utility.

Choices were made by pressing appropriately lettered keyboard keys, and followed by response outcomes ‘You Win X Points’ where X represented a numerical value outcome associated with the card. No win trials showed ‘zero’ points. It is critical to note, that although we aimed create choice alternatives that were equal in terms of expected value and overall net gain, achieving equality across the three choice options was practically not possible. This leaves UnO options as the rationally best option.

5.3.1.3 BIS/BAS Scale (Carver & White, 1994)

The BIS/BAS scale is a 20 item measure comprising BIS (7 items) and BAS (13 items) sensitivity along a 4-point scale (from 1, *disagree strongly* to 4, *agree strongly*). BIS items measure sensitivity towards cues of potential threat, punishment or non-reward. BAS items measure propensity towards potential rewards, and can be subdivided into three components: BAS-drive (4 items), which measures the pursuit of desired goals; BAS-fun-seeking (4 items), which measures the willingness to engage and seek out new and potentially rewarding events; BAS-reward responsiveness (5 items), which measures emotional reactivity towards positive events. As the current study focused on reward outcomes, we were only concerned with BAS measures. The BIS BAS scales show good internal reliability, ([alpha]s = .76, .66, .73 for BAS drive, fun-seeking and reward-responsiveness in a sample of college students respectively (Carver & White, 1994). In the present study, Cronbach’s alpha’s for BAS drive, fun-seeking and reward-responsiveness scales were .72, .79, .70 respectively.

5.3.1.4 Procedure

Participants undertook a single laboratory session that lasted approximately 45 minutes.

After providing written consent, participants were asked to complete the BIS/BAS scales and subsequently asked to perform two computerised card games. Participants were informed their goal was to win as many points as possible, as points would constitute their monetary prize.

In order to familiarise participants with the card options, participants were given a practice block and advised that the outcomes of the practice block did not count towards the final tally.

5.3.1.5 Practice Block

The practice block consisted of 60 trials (20 from each condition). Cards were presented pseudo-randomly, one at a time, ensuring two exposures to each reward amount in the uncertain utility condition. After each card presentation, participants pressed the 'A' key and observed the outcomes. At the end of the block, participants were asked to verbally describe the outcomes, to ensure they learned the contingencies. Note, participants were not given any descriptive information or instructions about what outcomes were possible, and only learnt this information from experience during the practice block. Participants were instructed to use this knowledge to maximise their gains, and were informed that there were no losses, and no money would be taken from them. Once the practice block was completed, participants were briefly asked to express their knowledge regarding the contingencies between the three shapes and reward outcomes before commencing the two monetary reward games. Participants who failed to grasp these contingencies were excluded from the analysis. Only one participant failed to show learning of contingencies and one participant failed to complete questionnaire measures, both were subsequently removed from analysis leaving $n = 82$.

5.3.1.6 Monetary Reward Games

Our decision paradigm consisted of two monetary card game tasks: a two-alternative forced choice task of 60 trials, and a free choice task of 40 trials. A trial counter on the right hand corner of the screen indicated the remaining trials within each task.

Our decision tasks were designed to incorporate two choice formats typically used within decision research. Previous inconsistencies between individual differences and behavioural choice may reflect differences in choice contexts (e.g. Kriesler & Nitzan, 2008). As such, the current study adopted the simplest form of binary forced choice and the form of ‘accept-or reject’ sampling employed by decisions from experience methodologies (see Rakow & Newell, 2010).

Forced Choice: Two cards were presented simultaneously, participants were instructed to choose either the left or right card, by pressing the marked keys (left = Z, right = M). Left-right options were counterbalanced and choice combinations were presented in a pseudo-random order, 20 choices for each combination (Safe vs. UnO; Safe vs. UnU; UnO vs. UnU). After each choice, a feedback screen appeared for 2 seconds indicating the outcome (win/no win) before the next trial began. Preference between binary choice options was assessed as the proportion of each option chosen within each choice pair (e.g. Out of 20 presentations, the total number of Safe options chosen within Safe vs. UnO choice pairs is 15. As a proportion, this equates to .75, and indicates a preference for Safe > UnO options).

Free Choice: Cards appeared sequentially in pseudo-random order. Participants were allowed 40 draws from an unlimited sequence. Participants were instructed to maximise their gains by choosing to accept or reject a card by pressing the marked keys (accept Z / reject M). Outcomes of rejected cards were not revealed, and were replaced by another card choice. Feedback for accepted cards was displayed for 2 seconds indicating the outcome and the trial deducted from the counter. Preference was assessed as the proportion of each option accepted out of the total number of presentations of that option, (e.g. number of Safe options accepted / total number of Safe accepted + rejected).

Upon completion of the two tasks, participants were debriefed and reimbursed for their participation. Further, participants were asked not to disclose the purpose or payment structure of the task to any others who might potentially take part in the study.

5.3.2 Results

Choice behaviour and personality scores for males and females were statistically equivalent. Observed data under both forced and free choice tasks deviated from normality (Kolmogorov-Smirnov $p < .05$). Data transformation did not correct this violation; therefore, non-parametric analyses were employed. An alpha level of .05 was used for statistical analyses, with Bonferroni correction applied for multiple comparisons.

5.3.2.1 Distribution of Preference

Forced choice: Comparison of participant's preferences were made using Wilcoxon Signed Ranks. For Safe vs. UnO and Safe vs. UnU choice pairs, participants significantly preferred Safe options over both UnO, $z = -3.1, p = .001, r = -.32$, and UnU alternatives, $z = -4.7, p < .001, r = -.50$. For UnO vs. UnU choice pairs, participants appeared indifferent, $z = -.70, p = .24, r = -.08$.

Free choice: Consistent with forced choice data, participants accepted significantly more Safe options compared to both UnO ($z = -6.0, p < .001, r = -.63$), and UnU

options ($z = -5.6$, $p < .001$, $r = -.59$), but again, showed no difference in acceptance between uncertain Outcome and Utility options ($z = -.17$, $p > .5$).

5.3.2.2 Individual differences: High vs. Low BAS

To explore overall BAS sensitivity and choice behaviour, participants were grouped into high BAS ($n = 43$) and Low BAS ($n = 46$) groups based on a median split of BAS total scores. Figure 5.1 illustrates the distribution of preference under forced choice for high and low BAS groups. As shown, the general pattern of preference observed at an overall group level was conserved, in that both high and low BAS groups show a greater preference for Safe over both UnO and UnU options. However, a one-way ANOVA between High and Low BAS groups revealed significant differences in the degree of preference within choices involving UnU options. For Safe vs. UnU choices, the high BAS group chose significantly fewer UnU options, and correspondingly, more Safe options compared to the low BAS group $F(1, 88) = 4.42$, $p = .038$. For UnO vs. UnU choices, the high BAS group chose significantly fewer UnU options, and correspondingly more UnO options relative to the low BAS group (mean = .54, SD = .29), $F(1, 88) = 5.30$, $p = .024$. Therefore, whilst overall group analysis suggests that UnO and UnU are treated equivalently within UnO vs. UnO choice pairs, BAS group analysis reveal UnU options are more/less preferable based on individual differences in BAS sensitivity.

Although comparison of high and low BAS groups with respect to free choice preferences revealed a greater acceptance of UnO options by high compared to low BAS groups, this difference did not reach significance ($p > .10$).

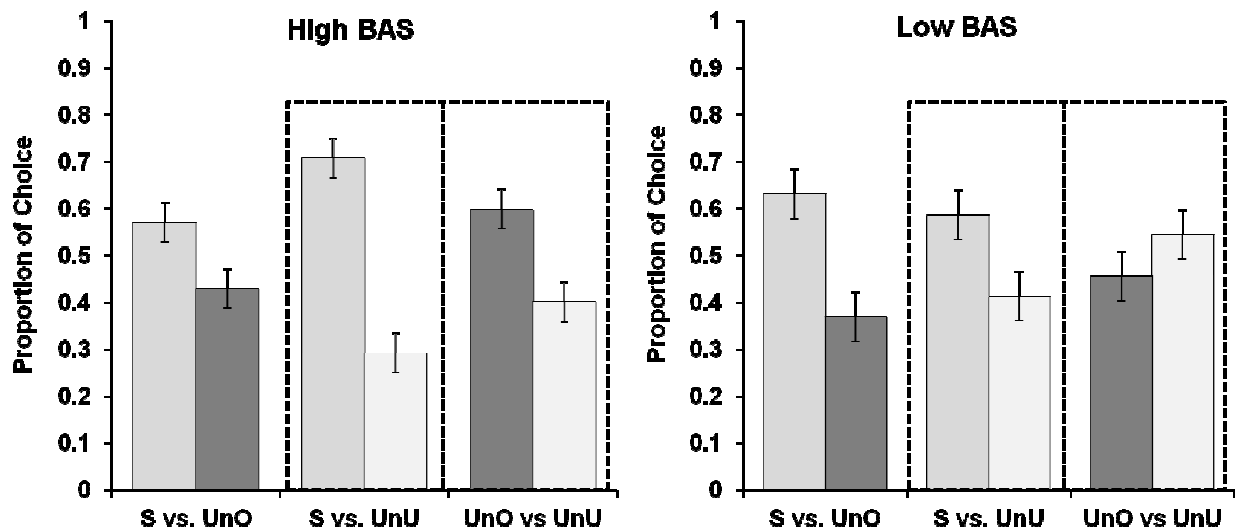


Figure 5.1. High/Low BAS group Distribution of Forced Choice preference. Mean preferences for choice pairs under forced choice task according to high (left panel) and low (right) BAS groups. Outlined boxes indicate choice pairs (Safe vs. UnU and UnO vs. UnU) that significantly distinguish between High and Low BAS groups. Error bars indicate \pm S.E.M.

Although Total BAS scores reflect individual's sensitivity towards cues of reward and non-punishment (Gray, 1990), more recent conceptualisations of the BAS maintain the three subscales of Drive, Fun-seeking and Reward-responsiveness cannot be reduced to a single factor (e.g. Voigt et al., 2009). Therefore, to explore whether independent factors of the BAS underlie the above observed preferences, non-parametric Spearman's Rank correlations between measures of BAS sub-scales and preference measures (both forced and free choice conditions) are reported in Table 5.2.

Table 5.2. *Spearman's correlation coefficients between BAS subscales and forced and free choice measures*

	1	2	3
1. BAS Drive			
2. BAS Fun-seeking	.53**		
3. BAS Reward	.36**	.30**	
4. % UnO (Safe vs. UnO)	.25*	.11	.12
5. % UnU (Safe vs. UnU)	-.06	-.23*	-.15
6. % UnO (UnO vs. UnU)	.14	.21^	.19^
7. % Safe accepted	-.08	-.03	.19
8. % UnO accepted	.22*	.18	.16
9. % UnU accepted	-.11	-.09	-.01

Note: Correlations are between BAS subscales, and proportions of choice option indicated (Safe = certain outcome likelihood/outcome utility; UnO = Uncertainty in Outcome Likelihood; UnU = Uncertainty in Outcome Utility) under forced choice (4-6) and free choice (7-9) tasks. ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the .05 level (2-tailed). ^ indicates coefficient approached significance, $p < .1$.

Under forced choice conditions, BAS drive scores were significantly positively associated with UnO preferences, with higher BAS Drive associated with greater preference for UnO > Safe option choice. Conversely, BAS Fun-seeking scores were significantly associated with choices involving UnU options, with higher Fun-seeking scores related to less preference for UnU options in Safe vs. UnU choices. Higher Fun-seeking also showed a trend towards a preference for UnO > UnU options. Under free choice conditions, only BAS drive scores were significantly associated with acceptance of UnO options.

5.3.3 Discussion of Experiment 1

Experiment 1 sought to establish a methodology for distinguishing between ‘*if*’ and ‘*what*’ uncertainties. This was achieved by operationalizing uncertainties of ‘*if*’ and ‘*what*’ as economic parameters of outcome occurrence (UnO) and utility (UnU), and relating them to components of BAS sensitivity.

Overall, both UnO and UnU alternatives evoked similar behavioural responses, being less preferable when a safe alternative was present. Furthermore, this hierarchy of preference was conserved across forced and free choice task formats. In addition, overall group analysis suggested participants chose UnO and UnU options equally when faced with UnO vs. UnU choices, and when choosing to accept UnO and UnU options, suggesting the two types of decision uncertainty are equivalent. However, individual differences in reward approach motivations suggest this may not be the case.

Classifying participants according to their overall BAS status, revealed significant differences where choice pairs involved UnU options. Specifically, a greater proportion of UnU options were chosen by the Low BAS group under contexts of Safe vs. UnU, and UnO vs. UnU choices relative to the high BAS group. Individuals with high BAS sensitivity are more prone to engage in approach behaviour and experience positive affect in situations with cues signalling rewarding opportunities (Carver & White, 1994). From this perspective, a lower preference for UnU options observed in the high BAS group suggests reward value may be reduced by uncertainty in reward outcome utility.

Parsing dimensions of the BAS revealed a positive relationship between BAS drive and UnO options. For both forced choices between Safe and UnO options, and free choice acceptance of UnO options, high BAS drive scores were positively associated with choice preference for UnO. Conversely, a relationship between BAS fun-seeking emerged for choices between Safe and UnU choices, with high scores of BAS fun-seeking being negatively associated with choice preferences for UnU options.

The driving force behind our distinction between UnO and UnU emerged from observations that BAS dimensions are predictive of a range of real world choice

behaviours. However, this relationship has not been borne out with the use of behavioural measures of ‘risk-taking’. Having established a distinction between uncertainties in outcome occurrence and outcome utility, a question to arise is how these different uncertainties map to commonly used behavioural measures of ‘risk-taking’.

The positive relationship between BAS drive and UnO choice preference is consistent with previous associations made between risky choice on gambling type tasks such as the Iowa Gambling tasks (IGT; Bechara, Damasio, Damasio, & Anderson, 1994) and high BAS sensitivity (Goudriaan, et al., 2006; Suhr & Tsanadis, 2007; van Honk, et al., 2002). In this respect, we would expect a similar relationship to emerge between our conception of UnO and IGT performance.

With regards to UnU choice preference, the negative relationship between BAS fun-seeking and UnU choice is of interest. Unlike BAS drive and reward-responsiveness which collectively represent motivational tendencies governed by reward sensitivity, BAS fun-seeking represents approach motivations that align more closely with dimensions of impulsivity (Dawe, Gullo, & Loxton, 2004; Heym, Ferguson, & Lawrence, 2008). Indeed, the relationship between BAS fun-seeking and choice behaviours concerned with immediate gratification are thought to reflect a reduced appraisal of future consequences (Franken & Muris, 2006).

The most widely used behavioural assessment of impulsive choice is the delay discounting paradigm (see Tesch & Sanfey, 2008), however, few studies have examined associations (or lack thereof) between BAS dimensions and DD performance. Nevertheless, given a greater aversion towards UnU options by participants scoring high on BAS fun-seeking, and the relationship between BAS fun-seeking and impulsive choice, we would expect UnU choice preferences would predict behavioural performance on measures of DD.

5.4 Experiment 2: Mapping ‘if’ and ‘what’ to ‘risky’ and impulsive’ decisions

Building on the methodology established in experiment 1, we considered how choices made under contexts of UnO and UnU predict behavioural performance on commonly used behavioural decision tasks.

The Iowa Gambling Task (Bechara et al., 1994) and delay discounting tasks represent two of the most widely used behaviour decision tasks used to explore risky and impulsive decision making. Whilst both tasks take a similar methodological approach, in that participants are required to make a forced choice between either one or several alternatives, the two tasks potentially differ in terms of the uncertainty they present.

Within the IGT, participants are faced with four decks of cards that offer small and large rewards and penalties. Through exploration of these decks, participants learn that two decks offer modest rewards and correspondingly, modest and infrequent penalties (advantageous decks), whereas the remaining decks, whilst providing larger rewards, are accompanied by larger penalties (disadvantageous). Subtracting the total number of disadvantageous from advantageous selections provides an index of risk taking.

However, recent studies have suggested early and later stages of IGT should be considered separately (Brand, Labudda, & Markowitsch, 2006; Brand, et al., 2007). Early stages reflect the failure to recognise risk given the limited explicit knowledge regarding outcome contingencies. Conversely, later stages reflect the acquisition of explicit knowledge of risk profiles associated with respective decks (Brand, et al., 2007; Harman, 2011; Upton, Kerestes, & Stout, 2011).

Building on findings from experiment 1, we hypothesised behavioural responses towards UnO but not UnU would predict behavioural performance on later stages of the IGT. Specifically, a greater preference for UnO over Safe alternatives would predict a greater propensity to make disadvantageous card selections during the later blocks of the IGT.

In contrast, performance on delay discounting tasks is considered synonymous with impulsive choice (Ainslie, 1975). Within delay discounting tasks, participants are presented with a series of choices between small rewards that are available immediately and larger rewards that are delayed. Studies have consistently shown that individuals prefer to receive rewards sooner rather than later, even when choosing delayed rewards provides the more optimal course of action. One account for such preferences is that the future is inherently uncertain, which leads to an intangible and abstract representation of reward value (Rick & Loewenstein, 2008; Trope & Liberman, 2003). Accordingly, impulsive choices may reflect an aversion towards ‘ambiguous’ poorly-defined outcomes. Considering this, and our hypothesis that UnU may prevent the construction of outcome expectancies, we expected preferences for UnU and not UnO to be associated with delay discounting performance. Based on findings from experiment 1, we would expect a greater preference for UnU over Safe alternatives would be associated with a tolerance for delayed rewards, and be observed as less discounting.

5.4.1 Methods

5.4.1.1 Participants

A sample of thirty-three ($n = 15$ male) University of Manchester (non-psychology) students with mean age $25 + 4$ years were recruited through an internal volunteer website on an opportunity basis. None of the participants had previously taken part in experiment 1. The study was approved by the local ethics committee, and participants were reimbursed upon study completion. All participants completed all three tasks.

5.4.1.2 Procedure

Each participant was individually administered the monetary reward game, and computerised versions of the IGT and a delay discounting task (order counterbalanced across participants). Upon completion of all the behavioural measures, participants were debriefed and reimbursed for their participation.

5.4.1.3 Monetary Reward Game

Based on results from experiment 1 and that behavioural preference on both IGT and DD tasks are elicited by forced choice, participants undertook only the forced choice block of the monetary reward game described in experiment 1.

5.4.1.4 Iowa Gambling Task (IGT: Bechara et al., 1994)

A version of the IGT was employed consistent with the payout structure described in Bechara et al., (1994). The IGT consists of 100 trials in which participants are required to choose a card from one of four available decks. Participants are provided with a starting bonus of £2000, and instructed to maximise their winnings by drawing cards from the four decks. Two of the decks (A and B) offer frequent high magnitude gains (e.g. £100), but are accompanied by frequent larger losses in the long run (e.g. -£250/ -£1250 respectively), and are referred to as disadvantageous. The remaining decks (C and D) offer modest immediate gains (i.e. £50), but also fewer and smaller losses (i.e. -£25 to -£75) and are referred to as advantageous.

Performance on the IGT was measured as the number of advantageous minus disadvantageous selections (i.e. decks [C+D]- [A + B]) subdivided across the 100 trials into five blocks of 20 trials: 1–20, 21–40, 41–60, 61–80, and 81–100. Higher scores reflect the use of a more advantageous strategy.

5.4.1.5 Delay Discounting Task

A computerised delay discounting task (Holt et al., 2003) was employed to deliver hypothetical choices between a small monetary reward available immediately, and a larger reward available after a specified delay. The objective of the DD task is to converge on a point of indifference (i.e. both alternatives are subjectively equivalent) between immediate and delayed alternatives across a series of delay periods. Indifference points can then be plotted to reveal a subjective value curve for a given reward across time and corresponding discount rate. In the current study for each choice, the delayed reward was always £10, and was available across one of 8 delays (now, 2 days, 30 days, 6 months, 1 year, 2 years, 5 years and 10 years).

To converge at an indifference point, an adjust-amount procedure was employed (Richards et al., 1999). Previous studies have shown discounting is moderated by whether adjustments are made in an ascending or descending manner (e.g. Robles & Vargas, 2008), we employed a neutral strategy by initialising choice trials with an immediate amount that was always half the value of the larger delayed alternative (i.e. £5). For subsequent choices, the amount of the immediate reward was adjusted based on participant's previous choice response. The sizes of adjustments made (either increase or decrease) were made according to a "half the difference" algorithm (see Du et al., 2002).

Both hyperbolic and exponential discount functions were fitted to data to establish consistency with previous reports (e.g. Green & Myerson, 2004). Subsequent analysis was based on the area under the curve (AUC) because this measure has good psychometric properties (Myerson, et al., 2001).

5.4.2 Results

5.4.2.1 Iowa Gambling Task Results

Figure 2 shows group mean IGT scores [advantageous – disadvantageous] across blocks of trials. As indicated, participants increasingly selected from advantageous decks across blocks of trials. A one-way ANOVA confirmed a significant effect of block, $F(4, 160) = 9.02, p < .001, \eta^2 = .43$. Planned contrasts revealed a significant linear trend, $F(1, 160) = 31.8, p < .001$. These results are consistent with previous findings from healthy student samples (e.g. Brand et al., 2007).

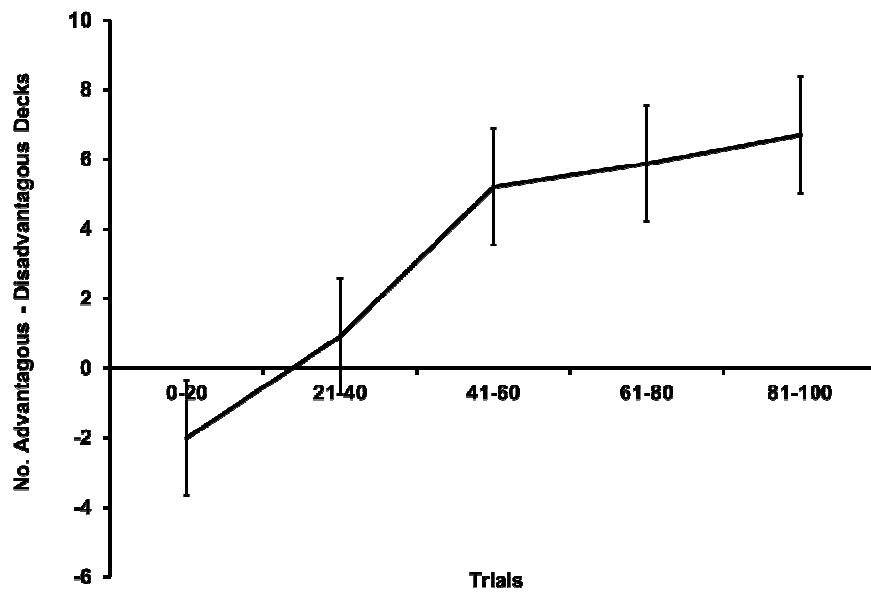


Figure 5.2. Mean IGT performance across blocks of trials as indexed by the number of advantageous–disadvantageous card selections. Error bars indicate \pm S.E.M

5.4.2.2 Delay Discounting Results

Consistent with previous reports, the subjective value of the delayed reward was reduced over time. Figure 5.2 shows group median indifference points for the delayed reward fit with both hyperbolic and exponential decay functions. For group data, R^2 values represent the variance account for by hyperbolic (.97) and exponential (.90) functions, and indicate the data were better characterised by a hyperbolic model.

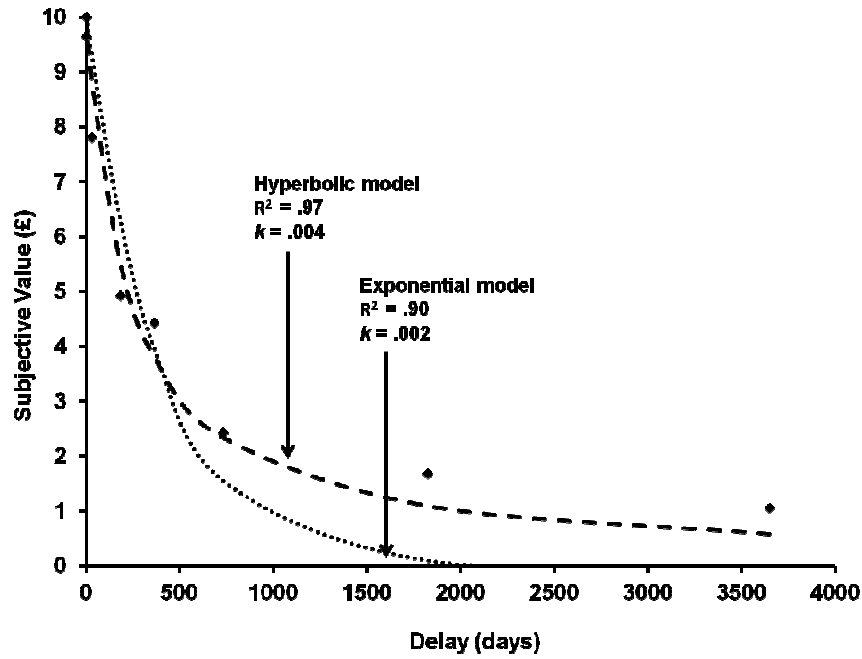


Figure 5.3. Group median indifference points for delayed £10 as a function of time. Curves represent model fit with hyperbolic and exponential decay functions.

Whilst a hyperbolic model provides a more superior fit to data, as indicated in Figure 5.3, at longer delays, decay functions overestimate discounting. Therefore, area under the curve (AUC) values were calculated for each participant, and used in subsequent analysis.

5.4.2.3 'If' and 'What' Results

The distribution of behavioural preference between choice pairs replicated results from experiment 1, with participants displaying a significant preference for Safe options over both UnO, $z = -2.9$, $p = .003$, $r = .51$, and UnU alternatives, $z = -3.1$, $p = .002$, $r = .54$, but no discernable preferences between Uno and UnU options, $z = -.67$, $p = .50$, $r = .12$.

5.4.2.3.1 Regression analysis

Two separate hierarchical linear regressions assessed whether participant's choice preferences for UnO and UnU contributed independently to the prediction of IGT and delay discounting performance (Table 5.3).

For IGT performance, the last block of trials was (81-100) was taken as the outcome dependent variable, as this later set of trials represents decision making under uncertainty based on explicit information (Brand et al., 2007).

Choice preference for UnO (i.e. the proportion of UnO options chosen within Safe vs. UnO choice pairs) were entered first, and accounted for a significant proportion of the variance in IGT performance. The negative relationship between participant's preferences for UnO and IGT performance indicates participants displaying a greater preference for UnO options made fewer selections from advantageous decks, and correspondingly, made more selections from disadvantageous decks. Addition of participant's preferences for UnU (i.e. the proportion of UnU options chosen within Safe vs., UnU choice pairs) did not significantly improve the model fit.

For delay discounting performance, tolerance for UnO did not emerge as a significant predictor of AUC values. However, the addition of participant's tolerance for UnU significantly improved the model fit. Given negative values of UnU indicate a preference for certainty over UnU options, the positive relationship between participant's tolerance for UnU and AUC values suggest that participants displaying greater tolerance for UnU options also discounted less.

Table 5.3. Hierarchical regression analysis: variables predicting IGT and delay discounting performance

a) IGT proportion of advantageous selection in block 5

Step & Variable	B	SE B	β
Constant	10.99	2.49	
Preference for UnO	-12.70	5.82	-.38*
Constant	10.30	2.83	
Preference for UnO	-13.93	6.33	-.41*
Preference for UnU	3.46	6.37	.10

Note: $R^2 = .14$ step 1, ($p < .05$); $\Delta R^2 = .008$, step 2 (n.s); * $p < .05$

b) AUC values

Step & Variable	B	SE B	β
Constant	.24	.04	
Preference for UnU	.03	.09	.06
Constant	.18	.04	
Preference for UnO	-.07	.09	-.15
Preference for UnU	.29	.09	.56 **

Note: $R^2 = .007$ step 1, (n.s); $\Delta R^2 = .28$, step 2 ($p = .002$); ** $p < .01$

5.4.3 Discussion of Experiment 2

Experiment 2 sought to map behavioural preferences for UnO and UnU with risky and impulsive choices based on IGT and DD performance. Consistent with our predictions, only behavioural preferences towards UnO predicted end block IGT performance. Conversely, only behavioural preferences towards UnU predicted DD performance.

5.5 General Discussion

The two experiments reported in the current study demonstrate ‘*if*’ and ‘*what*’ uncertainties operationalised as uncertainties about outcome occurrence (UnO) and outcome utility (UnU), reflect distinguishable sources of uncertainty based on the ability to form outcome expectancies, and therefore, motivational approach strategies.

5.5.1 *Creating variability within utility as a source of uncertainty*

Our primary objective was to examine the effect uncertainty created in outcome utility has on choice preferences in isolation from the impact of uncertainty in outcome likelihood. This was achieved by delivering a predictable positive outcome (90% win probability) with a large distribution of possible reward utilities (ranging from 3-99 points). Our rational being that, despite exposure to each possible utility outcome during a practice session, we considered forming an accurate representation about ‘*what*’ to expect would prove to be cognitively demanding, being reliant to some extent on working memory capacity (see Hertwig, Barron, Weber, & Erev, 2006; Kareev, Arnon, & Horwitz-Zeliger, 2002).

Consistent with this view, participants chose a greater proportion of Safe relative to UnU options. This observation suggests that in spite of guaranteeing a rewarding outcome, there may be a cognitive cost to not knowing ‘*what*’ and is a novel concept to decision research, which would benefit from further exploration.

5.5.2 *Distinguishing utility and outcome uncertainties*

For Safe versus UnO choices, both options offered a certain utility (45 or 101 points respectively), but differed in terms of outcome likelihood (90 % and 50 % respectively). This resulted in expected values of (40.5 and 50.5 respectively), making UnO rationally the more attractive option. However, participants significantly preferred the Safe (less profitable) option. This is consistent with the observation that individuals are ‘risk-averse’ for probabilistic gains, preferring outcome certainty even when the alternative is higher in expected utility (Kahneman & Tversky, 1979).

Across both Experiment 1 and 2, overall group analysis revealed both uncertainty in outcome utility and outcome occurrence were both less preferable when a safe alternative was present. Furthermore, in experiment 1 we found this hierarchy of preference was conserved across decision task formats suggesting the two types of decision uncertainty are equivalent. However, differential associations between choice preferences for UnO and UnU and sub-components of the BAS in experiment 1, and behavioural performance on measure of the IGT and DD in experiment 2 suggest this may not be the case.

Consistent with recent conceptualisation of the BAS as a two-component model (e.g. Dawe et al., 2004), results from experiment 1 revealed a distinction between BAS drive and fun-seeking and their respective associations with preferences UnO and UnU options.

High BAS drive scores were associated with choice preferences for UnO options, in the context of a Safe option alternative, and a greater propensity to accept rather than reject UnO options. This is consistent with conceptions of BAS drive as a measure of the strength to which potentially large rewards guide behaviour and decision strategies that optimise reward attainment (Hickey, Chelazzi, & Theeuwes, 2010b; Scheres & Sanfey, 2006). Our observations are also consistent with previous associations reported between BAS drive and tendencies towards probabilistic ‘risky’ decision making (Kim & Lee, 2011; Suhr & Tsanadis, 2007). Therefore, where choice alternatives differ in terms of outcome occurrence, variation in reward motivation and not expected utility determine decision strategies to maximise reward. The absence of a relationship between drive and choices involving UnU options suggests implementing decision strategies to optimise reward is highly dependent on intact reward representations. For individuals high in BAS drive, when pursuing goals, being able to represent and predict ‘*what*’ outcome will occur carries greater informational value, than the absence of knowing ‘*if*’ a reward will occur.

A relationship between BAS fun-seeking and UnU choices supports our hypothesis that uncertainty about ‘*what*’ outcomes will occur impacts the ability to represent reward. High BAS fun-seeking was associated with the avoidance of UnU options within the context of a Safe option alternative. BAS fun-seeking, reflects an approach dimension affiliated with the tendency to act impulsively, (Dawe, et al., 2004; Heym, et al., 2008; Miller, Joseph, & Tudway, 2004; Quilty & Oakman, 2004), and correlates with ‘risky’ lifestyle choices that are concerned with immediate gratification, e.g. alcohol and substance use (Franken & Muris, 2005). From this perspective, the inverse relationship between fun-seeking and UnU choices suggests the need for immediate gratification may place a premium on ‘*what*’ rewards will be received, rather than ‘*if*’ rewards will occur.

In this sense, high BAS sensitivity promotes ‘risky’ choices in contexts where outcome expectancies can be constructed on the basis that ‘*what*’ is known and of high value. Conversely, high BAS sensitivity promotes ‘impulsive’ choice, in contexts where outcome expectancies are hindered by an inability to represent ‘*what*’ to outcomes to expect.

Findings from experiment 2 provide support for this view. Later stages of the IGT reflect the use of decision strategies that are based on explicit knowledge regarding the pay-out structures associated with each deck of cards (Brand et al., 2007), and correlate well with alternative behavioural measures of risk taking such as the Balloon Analogue Task (e.g. Upton et al., 2011). Such ‘risky’ decision making is suggested to rely on specific neural systems that sub-serve executive functions (Brand, et al., 2007), and therefore reflect cognitive and deliberative processes.

Within our conceptualisation of UnO and UnU, we suggested that these types of uncertainty could be distinguished based on their differential impact in the construction of outcome expectancies. More specifically, we proposed that where uncertainty concerns the occurrence of an outcome, individuals retain the ability to generate an explicit representation of *what* outcome to expect. In contrast, uncertainty created by a large distribution of possible outcomes hinders the ability to construct outcome representations, and thus outcome expectancies. Consistent with our hypothesis, results

from experiment 2 demonstrated that participants who preferred UnO relative to Safe alternatives, also made more disadvantageous, i.e. risky, card selections during the last block of IGT trials.

Consistent with our conception of UnU as reflecting an inability to form outcome expectancies, preferences for UnU options did not predict IGT performance. They did, however contribute to performance on a delay discounting task. Although delay discounting tasks are generally used to index impulsive choice, the precise mechanisms underlying discounting are unclear. One intuitive perspective is that preferences for immediacy arise as a function of the inherent uncertainty entailed by delays. For instance, future outcomes may be uncertain in terms of whether they will occur or not, and if so when they will occur, and what they will consist of. From this perspective, future outcomes represent an intangible quality (Rick & Loewenstein, 2008) such that where decisions involve future outcomes, there is lack of explicit knowledge regarding *what* to expect. Our observation that UnU, but not UnO preferences predicted delay discounting performance support this view. Specifically, participants who preferred UnU options over Safe alternatives also demonstrated larger AUC values that are indicative of less discounting. This result holds important theoretical implications for delay discounting as they suggest the ability to tolerate an uncertainty about *what* rewards will occur may convey an ability to consider decision outcomes that lie in future.

It is worth noting that BIS/BAS measures were not incorporated in experiment 2, and presents a limitation for experiment 2 results. On the one hand, their use may have further substantiated findings from experiment 1. However, had the BIS/BAS scale been used to predict either or both IGT and DD performance would have yielded inconclusive results. For instance, had BAS drive alone proved a significant predictor of UnO preference and IGT performance would be consistent with the view that BAS drive predict naturalistic ‘risky choice (see Voigt et al., 2009). However, studies of behavioural ‘risky’ choice reveal BAS fun-seeking as a more appropriate predictor of IGT performance. Although, in such cases, IGT performance is defined in terms of net scores rather than by block. As such, whilst a limiting factor for the current study, the

use of BAS subscales in predicting performance on behavioural measures of ‘risky’ choice require further validation.

5.6 Conclusion

The current study we suggested uncertainties in ‘*if*’ and ‘*what*’ reflect distinct types of decision uncertainty based on their differential impact on the construction of explicit outcome representations. Across two experiments, we showed that by operationalizing *if* and *what* uncertainties along economic dimensions of outcome likelihood and outcome utility provides a useful methodological approach for relating individual differences in motivational approach tendencies. Furthermore, our findings offer a potential means for distinguishing between risky and impulsive choice on commonly used behavioural decision tasks.

CHAPTER 6: External Information about Potential Outcomes modifies Trait-Predicted Behavioural Preference

6.1 Abstract

Decision making involves uncertainties about '*if*' and '*what*' outcomes will occur. Whilst personality factors are shown to predict behavioural choice preferences under uncertainty, preferences are also subject to change. In this study we examine the stability of trait predicted choice preferences for uncertainties about '*if*' and '*what*' and the mechanisms through which preference change may be induced using a model of social influences.

Sixty university undergraduate students undertook a novel behavioural task which operationalised '*if*' and '*what*' as uncertainties in outcome occurrence and outcome utility, within the context of socially provided information. Results demonstrated that in the absence of socially provided information, individual difference in neuroticism predicted behavioural preferences for likelihood and utility. Whilst dis-confirmatory socially provided information had a general impact in shifting trait-predicted preferences, this impact was greater when information concerned outcome utility relative to the likelihood of occurrence. This differential impact was supported by behavioural reaction times, which were modulated as a function of information valence (win/loss) for occurrence and not for utility information.

The present findings provide important contributions for understanding how individual differences and contextual variations shape behavioural choice preference in a framework that considers information availability within decision making.

6.2 Introduction

For many of the decisions we face, we must consider both the likelihood and the distribution of potential consequences. Unfortunately, such information is not always readily available; we lack complete information about ‘*if*’ outcomes will occur, and ‘*what*’ they will consist of.

Individual difference approaches take the view that stable underlying traits provide a proximate mechanism through which behavioural preferences for uncertainty manifest (e.g. Mishra & Lalumière, 2011). Consistent with this view, we have previously shown that in the context of a safe choice alternative, individual differences in components of trait reward sensitivity distinguish preferences for uncertainties about ‘*if*’ and ‘*what*’ (Chapter 5). However, choice preferences are not stable, but are subject to contextual variables in the decision environment (Lichtenstein & Slovic, 2006). The extent to which underlying trait-predicted preferences and sensitivity to contextual variables interact remains unclear and greatly debated (Figner & Weber, 2011; Warren, McGraw, & Van Boven, 2011).

The current study addresses this issue by examining the stability of trait predicted preferences for ‘*if*’ and ‘*what*’ and the mechanisms through which preference change may be induced. Our theoretical framework is based on the notion of Bayesian inference, and the basic premise that people are motivated to reduce uncertainty (Sorrentino, 2000) by seeking and acquiring additional information (Berger & Calabrese, 1975; Kellermann & Reynolds, 1990). Such information may be gathered from social sources such as advice or recommendations from others, and/or from direct experience (Collins, Percy, Smith, & Kruschke, 2011).

6.2.1 Theoretical Framework

6.2.1.1 Bayesian updating based on acquired information about ‘if’

Within a Bayesian framework, decision making reflects the process of belief updating with sole objective of reducing the amount of uncertainty. On the basis of observations, initial beliefs, or priors are updated in manner that shapes a new set of beliefs, or a posterior, which carries less uncertainty.

Where decisions involve known outcome values, but are uncertain in terms of their likelihood, observations enable the fine tuning of beliefs about ‘if’ a known outcome will occur. For example, consider a decision-maker choosing whether to bet on the chance of obtaining a heads with the toss of a coin. His prior will comprise a belief about what outcomes are possible (heads or tails), for which there is zero uncertainty, and some belief about the chances of obtaining a heads. All things considered, he should have no reason to expect that the coin is unfair, and therefore believes there to be a 50 % chance that the next toss should be heads. In this way, his observations contribute towards refining his accuracy about the *likelihood* of a heads occurring. After directly observing four tosses that land on tails however, our decision maker revises his prior beliefs to consider the coin is actually unfair, and adjusts his predictions concerning the likelihood of a particular outcome.

Evidence that such likelihood information can be acquired from observations has been observed using sequential sampling paradigms with risky outcomes (e.g. Hertwig et al., 2004). For example, limited sampling sizes (Fox & Hadar, 2006; Hau, Pleskac, Kiefer, & Hertwig, 2008; Ralph Hertwig, Barron, Weber, & Erev, 2004; Rakow, Demes, & Newell, 2008) and variation in sampling strategies (Hills & Hertwig, 2010) will necessarily interfere with the experience of rare (i.e. low probability) outcomes. And yet, decision makers are still capable of providing well calibrated frequency estimates for such rare events (Fox & Hadar, 2006; Ungemach, Chater, & Stewart, 2009), consistent with the view that tracking frequencies is a relatively automatic process which individuals are adept (Zacks & Hasher, 2002).

Therefore, in the context where a limited set of ‘*what*’ outcomes are possible and known, direct observations enable the indirect acquisition about ‘*if*’ outcomes will occur. Such information is both sufficient and preferable over accompanying descriptive information (i.e. objective outcome values and probabilities) for making decisions (Jessup, Bishara, & Busemeyer, 2008; Lejarraga, 2010), as unlike descriptive information which requires cognitive effort to ‘unpack’, experienced information represents concrete and more easily accessible knowledge (Lejarraga & Gonzalez, 2011).

6.2.1.2 Bayesian updating based on acquired information about ‘what’

Returning to our Bayesian decision maker, let us reconsider a situation in which a single action may lead to more than two possible outcomes. Through the same process, observations provide a means to reduce uncertainty about *what* outcome values may be expected. For example, on arriving at the supermarket, our decision-maker discovers his favourite brand of baked beans is out of stock. Nevertheless, there is an abundant choice of alternative brands, for which he has no particular knowledge, but from which he must choose. Based on the objective to reduce uncertainty about ‘*what*’ to expect, he has two alternative strategies; try each one (which is constrained in terms of time, effort, and not least of all digestion), or seek the advice of others.

Indeed, in real world contexts, the latter is more often the case, as people tend to reduce uncertainty by ‘exploiting the wisdom of others’ (Budescu & Rantilla, 2000; Festinger, 1954; Yaniv & Choshen-Hillel, 2011).

Whilst people generally prefer to adopt the perspective of others who they deem as more credible, accurate, and expert (Bonaccio & Dalal, 2006, 2010; Budescu & Rantilla, 2000; Leon Festinger, 1954; Yaniv & Choshen-Hillel, 2011; Yaniv & Milyavsky, 2007), naïve advice can be just as influential (Harvey & Fischer, 1997; Schotter, 2003; Yaniv, 2004b).

This is primarily because whether judgements concern the prediction of numerical (e.g. how many calories in a bowl of cereal) or more abstract (e.g. which movie to see) outcomes, uncertainty resides in knowing *what* outcomes of their current choices will be

more favourable, in terms of either accuracy, or pleasure. Advice provided from others, especially those who are similar (e.g. Gino, Shang, & Croson, 2009; Van Swol, 2011), “bridges an informational gap” (Yaniv, Choshen-Hillel, & Milyavsky, 2011, p. 118) by instilling greater confidence about *what* to expect.

6.2.2. *The Current Study*

In this study, we take the view that uncertainty reflects a state of incomplete information about ‘*if*’ and ‘*what*’ outcomes may occur. Having previously established behavioural preferences for uncertainties about *if* and *what* are distinguishable on the basis of personality traits, our objective here is to address how such preferences may be altered by socially provided information.

In the context of no additional information, we predict that personality traits will determine relative preference for either ‘*if*’ or ‘*what*’. However, when contextual changes alter the level of information available, preference changes will arise. Critically, preference changes will reflect the differential impact of the type of additional information provided. Our predictions for preference changes are based on our previous suggestion that *if* and *what* are distinguishable on the basis of their ability to construct outcome expectancies.

Considering outcomes where information about ‘*if*’ is unknown, the ability to track frequencies of outcome occurrence providing outcome values are known and restricted enables an automatic representation (not necessarily accurate) of likelihood, i.e. a posterior belief about likelihood is achieved via experience. Therefore, providing a recommendation of as to what a significant other experienced should be redundant, in that it provides no additional information, and does not produce a change in preference.

However, where information about ‘*what*’ is absent, tracking the frequencies of multiple outcomes is not feasible, such that updating a prior to reduce uncertainty presents a greater cognitive challenge. In this sense, any information concerning *what* to expect will be beneficial. Therefore, recommendations from others should carry great weight, and result in significant changes in preference relative to contexts with no information.

In this manner, knowing ‘*if*’ and ‘*what*’ may reflect different qualities of information, and as such, their absence carries different cognitive costs for a decision maker

6.3 Method

6.3.1 Participants

Sixty University of Manchester (non-psychology) students (31 females), mean age 22.5 (SD = 2.9) years were recruited through an internal volunteer website on an opportunity basis. All participants provided informed consent, and the study was approved by the University local ethics committee.

6.3.2 Monetary Reward Game Stimuli

Participants played a computerised monetary reward game programmed using E-Prime (PST Inc, Sharpsburg USA). Two playing card shapes (diamonds and spades) which formed the game cards were presented on a white background, instructions, information and response outcomes were typed in black. The appearance of the two cards shapes on left and right hand sides of the computer monitor were counterbalanced across trials.

The two card shapes were associated with a probability of winning (outcome) with a range of reward points (utility) that characterised two option conditions: Uncertainty in Outcome occurrence (UnO) and Uncertainty in Utility (UnU) and are described in Table 6.1.

The whole game comprised 120 trials of forced choice pairs between UnO and UnU, which were subdivided across three information conditions: no information, UnO-information and UnU-information. There were 40 trials of each condition, which were presented in pseudo-random order.

Table 6.1 Choice options and associated probability/utility contingencies.

Choice	Probability of	Utility of outcome	Expected
Option	Outcome (%)	Win/Loss (points)	Value
UnO	50	170/ 130	20
UnU	90	3, 5, 8, 15, 22, 32, 52, 70, 92 / 99	20

UnO: Uncertainty in outcome likelihood; UnU: uncertainty in Utility.

No information: Both UnO and UnU were presented with no addition information. These choice trials provided a control condition for baseline preferences between UnO and UnU options.

UnO-information: Within UnO vs. UnU choice pair, the UnO option was presented with either win or loss related information in the form of “When other students chose this card, they WON/LOST X points”. Where win information accompanied UnO options, x represented 170 points. Where loss information accompanied UnO options, x represented 130 points.

UnU-Information: Within UnO vs. UnU choice pair, the UnU option was presented with either win or loss related information in the form of “When other students chose this card, they WON/LOST X points”. Where win information accompanied UnU options, x represented one of the possible UnU values listed in Table 6.1 (The value chosen was based on a random selection without replacement). Where loss information accompanied UnU options, x represented 99 points. In both information conditions there were equal numbers of win/loss trials.

6.3.3. Personality

Personality was measured using the NEO-Five Factor Inventory (NEO-FFI; Costa & McCrae, 1989). The NEO-FFI consists of 60 items, all of which are 5 point Likert-type scales that range from “strongly disagree” to “strongly agree”. Items comprise statements representative of the “Big Five” personality factors including Neuroticism (N) the tendency to experience a heightened sensitivity to negative stimuli and negative emotionality, such as worry and anxiety; Extraversion (E), the tendency for being concerned with or responsive to things external to oneself and to engage in social activities Openness to Experience (O), the tendency toward being imaginative, open to new experiences, and having a broad range of interests; Agreeableness (A) the tendency to be pleasant and accommodating in social situations as well as a general orientation towards experiencing empathy, warmth, and generosity toward others, and Conscientiousness (C) the tendency toward having good impulse control, being dependable, reliable, organized, and mindful of details. Reliability indexes between .72 and .087 have been reported within British samples (see Egan, Deary & Austin, 2000). In the current study, Cronbach’s alphas were .86, .82, .75, .64, and .76 for the N E O A and C scales respectively.

6.3.4 Procedure

Participants undertook a single laboratory session which lasted approximately 30 minutes. After proving written consent, and completing personality measures, participants were provided with instructions about how to play the card game and given a practice session in order to familiarise themselves with the procedure.

The practice session consisted of 24 trials of choices between UnO and UnU options with no information. Participants were advised that the outcomes of the practice block did not count towards the final tally.

Upon completion of the practice trials, participants were informed their goal was to win as many points as possible in the card game, as these points would be converted into monetary payment and constitute their monetary prize for taking part. Unbeknown to participants, all participants received the same payment of £5 for taking part.

Participants were also informed that on some trials, they would be provided with information about choices and respective outcomes made by other students who were similar to themselves. They were told this information was provided with no underlying motive, and that they were free to either use it or dismiss it as they wished.

For both practice trials and the card game, choices between UnO and UnU options were made by pressing the left and right mouse buttons respectively (the mapping of left and right buttons with UnO and UnU options was counterbalanced across participants). Once a choice had been made, feedback on the outcome valence and value of their chosen option was displayed, that was consistent with the payout structure described in Table 1, and followed by the next trial in the sequence.

Once all trials (120 in total) had been completed, participants were debriefed and reimbursed for taking part.

6.3.5 Analysis

The current study was interested in the impact of provided information regarding potential outcomes on choice preferences for UnO and UnU options. To examine this impact we measured both behavioural preference and reaction time data in response to UnO vs. UnU choices with and without information and according to the valence of information (win/loss) and the option associated with information (UnO/UnU).

For behavioural preference data, the proportion of UnO and UnU chosen were calculated within choice pairs across all conditions. Given the selection of UnO and UnU are dependent, and the majority of participants preferred UnU (see results) when no information was present, the proportion of UnU chosen when no information was present served as a baseline measure for preference. Changes in preference were calculated as the difference in proportion of UnU options chosen across information conditions [UnU-no information – UnU-information conditions]. The sign of the difference scores (+/-) indicates the direction of preference, with negative values always indicating a reduction in UnU choice preference.

For reaction time data, the time from presentation of choice options to the inputting of responses (left/right mouse buttons) was measured as the reaction time (RT). As the provision of information relative to no information would naturally require greater cognitive resources, only RTs in response to information conditions were compared. RTs occurring below a 100 ms threshold representing anticipation errors (Mir et al., 2011) were removed from analysis (.01% rejected trials). All data analysis was performed using SPSS for Windows version 16.0.

6.4 Results

6.4.1 Behavioural Choice

Table 6.2 presents mean (SD) proportion of UnU and UnO options chosen across information conditions, and the difference in proportion of UnU options chosen.

As indicated by the difference in UnU options relative to baseline UnU choice, the presentation of information had a significant effect on the direction of preference between UnO-UnU options, $F(4, 236) = 15.0$, $p < .001$, $\eta^2 = .20$. Post-hoc Pairwise comparisons Bonferroni corrected for multiple comparisons revealed that relative to baseline preferences, the significant effect of information in changing the direction of preference were driven by UnO-win ($p = .001$) and UnU-loss ($p = .003$) information conditions.

Table 6.2. Mean (SD) choice option preference, proportion change in UnU option choice from baseline preference across information conditions

Information Condition	Proportion UnO	Proportion UnU	Change from Baseline
	M (SD)	M (SD)	M (SD)
No Information	.45 (.16)	.56 (.16)	
UnO - Win	.57 (.20)	.43 (.20)	-.12 (.22)**
UnO - Loss	.40 (.19)	.60 (.19)	.05 (.21)
UnU- Win	.37 (.19)	.63 (.19)	.08 (.21)
UnU - Loss	.57 (.22)	.43 (.22)	-.12 (.24)**

Note: For changes in preference from baseline UnU choice, sign indicates direction of change, with negative values indicating a reduction in UnU choice. Positive values indicate no change or increased selection of UnU options relative to baseline. ** $p < .001$ Bonferroni corrected for multiple comparisons.

The impact of information [UnO-win and UnU-loss] conditions in changing the direction of preference reflected the incongruent nature such information holds relative to the group's initial preference orientation which favoured UnU > UnO options. However, a proportion of participants ($n = 21$) displayed an initial baseline preference for UnO > UnU.

Therefore, to further examine whether incongruent information in general or information type (UnO/ UnU) impacted choice in the same way, changes in preference (measured as the difference in UnU choice relative to baseline) were made according to whether information conditions were congruent or incongruent with baseline preference. Participants changes in choice preference (i.e. difference in UnU choice across conditions relative to baseline) were subjected to a 2 (information type: UnO, UnU) x 2

(congruency: congruent, incongruent) repeated ANOVA. The analysis revealed a significant main effect of congruency, $F(1, 57) = 5.9$, $p = .02$, $\eta^2 = .10$, with incongruent information resulting in greater changes in UnU choice. There was no main effect of information type, $p > .10$. However, an interaction between congruency and information type approached significance, $F(1, 57) = 3.9$, $p = .052$, $\eta^2 = .06$. This interaction is described in Figure 6.1, and suggested the impact of incongruent information in shifting baseline preferences for UnU appears greater for UnU compared to UnO information.

Post-hoc t-tests, Bonferroni corrected for multiple comparisons ($\alpha = .012$) confirmed this, as changes to baseline preference for UnU did not differ significantly between congruent and incongruent UnO information, $t(57) = .83$, $p = .41$. Furthermore, the difference between changes in preference under incongruent UnU and UnO information types did not reach significance, $t(57) = .19$, $p = .06$. However, incongruent UnU information did result in significantly reducing baseline preferences relative to congruent UnU information, $t(57) = 4.1$, $p < .001$. Therefore, UnO information has less impact on shifting initial baseline preference when it confirms or disconfirms initial baseline preference compared to UnU information.

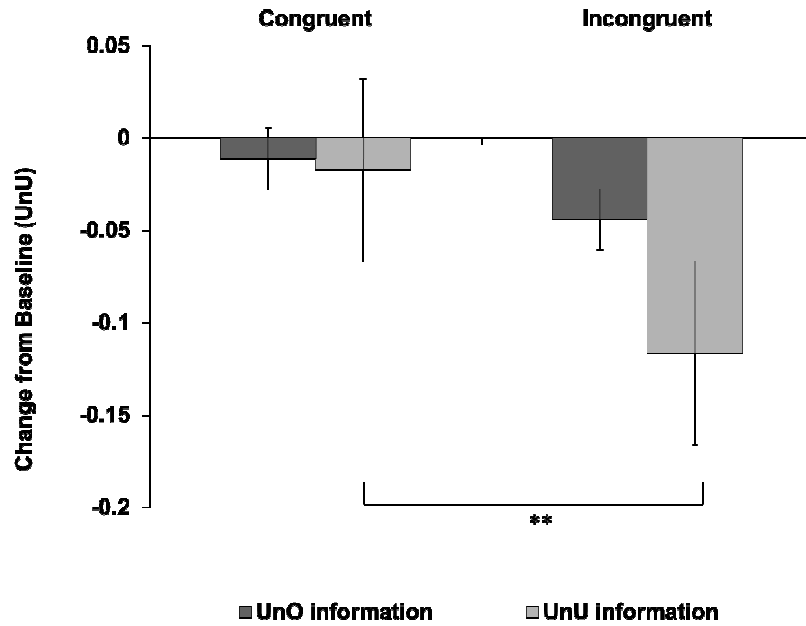


Figure 6.1. *Congruency \times information type interaction.* Graph shows change in baseline preference based on uncertain utility (UnU) choice as a function of whether information presented was congruent with baseline preference orientation and by information type. Changes from baseline preference reflect the difference between UnU choice in the context of no-information and UnU choice across information conditions, with negative values indicating a reduction in UnU choice. Error bars indicate \pm S. E. M. ** $p < .001$.

6.4.2 Individual Differences

Having shown that individuals showing an initial baseline preference for either UnO or UnU responded differentially to information which either confirmed or disconfirmed their preference, we questioned whether the differential impact of information observed by preference groups related to underlying personality dimensions as measured by the NEO-FFI.

A one-way ANOVA between baseline preference groups and NEO-FFI scores revealed preference groups differed along the dimension of neuroticism, $F(1, 52) = 7.95$, $p = .007$, with the UnU preference group displaying significantly higher Neuroticism scores ($M = 22.2$, $SD = 7.5$) compared to the UnO preference group ($M = 16.0$, $SD = 7.1$). Preference groups did not differ on any of the remaining factors of Extraversion, Openness, Agreeableness and Conscientiousness (all p 's $> .5$).

A linear regression analysis was used to further clarify the extent to which neuroticism predicted participant's behavioural choices. The analysis indicated that, in the absence of external information, neuroticism explained 12% of the variance ($R^2 = .12$, $F(1, 54) = 6.88$, $p = .01$), and significantly predicted behavioural choice preferences for UnU compared to UnO options ($B = .02$, $SE_B = .006$, $\beta = .40$, $p = .01$). In the presence of external information, neuroticism was not a significant predictor of choice preference, or changes in preference from baseline (all p 's $> .5$)

6.4.3 Reaction Times

In terms of responding to the presentation of informed options, participants displayed slower reaction times to choices between UnO and UnU options when information accompanied choice options ($M = 1547.4$ ms, $SD = 758.1$, collapsed across information conditions) relative to choices with no information ($M = 1039.5$ ms, $SD = 419.1$). This is consistent with the additional processing required in reading choice option information, and therefore only comparisons of RTs across information conditions are conducted.

Overall group analysis of reaction times revealed a significant main effect of information valence on RTs, with faster RTs in response to choices presented with win compared to loss-related information, $F(1, 59) = 5.89$, $p = .018$, $\eta^2 = .10$. Although RTs did not differ with respect to the option associated with information ($p > .4$), there was a significant interaction between option and information valence, $F(1, 59) = 4.30$, $p = .04$, $\eta^2 = .07$. As shown in Figure 6.2, this interaction was driven by a significant difference in RTs between win and loss information accompanying UnO options, $t(59) = -3.52$, $p = .001$, but not UnU options, $t(59) = -.44$, $p = .66$.

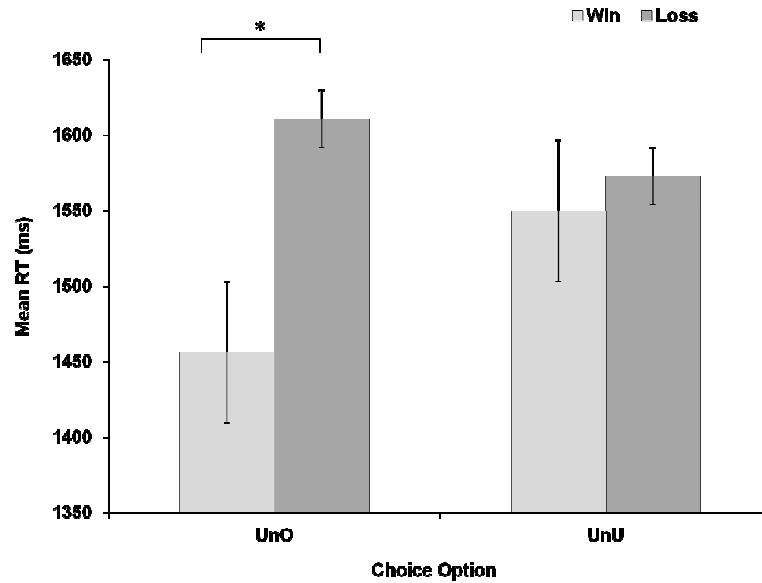


Figure 6.2. Mean reaction times (ms) in response to presentation of win/loss informed options: Uncertain Outcome (UnO) or Uncertain Utility (UnU) choice options. Error bars represent \pm S.E.M. * $p < .05$.

6.5 Discussion

This study was motivated by two central objectives that extend our previous distinction between uncertainties about ‘*if*’ and ‘*what*’. Firstly, to test the stability of personality driven behavioural preferences for ‘*if*’ and ‘*what*’ when additional information about the consequences of the choice are provided, here in the form of peer knowledge. Secondly, to test how knowledge about ‘*if*’ and ‘*what*’ can be construed as different qualities of information.

The results demonstrated that in the absence of socially provided information, individual difference in neuroticism predicted behavioural preferences for choices between outcomes uncertain in terms likelihood (UnO) and utility (UnU). Whilst incongruent socially provided information had a general impact in shifting baseline preferences, this impact was greater when information concerned UnU relative to UnO outcomes. This differential impact was supported by behavioural reaction times, which

were modulated as a function of information valence (win/loss) for UnO and not UnU information.

6.5.1 The (in)stability of behavioural preferences: personality & context

6.5.1.1 Baseline preferences and personality

Consistent with previous findings (e.g. Mishra & Luminer, 2011; Chapter 5), we observed that in the absence of external inputs, behavioural preferences were significantly predicted by personality. Specifically, high scores of trait neuroticism predicted preferences for UnU over UnO outcomes.

Neuroticism is a dispositional tendency to experience negative affect (e.g. Costa & McCrea, 1992). Individuals who score high on trait measures of neuroticism tend to be less emotional stable, responding poorly to environmental stress, and interpret situations as threatening (Carver, Sutton, & Scheier, 2000). In terms of decision making, such tendencies manifest in behavioural choices and strategies that minimise or delay potentially negative outcomes (Germeijs & Verschueren, 2011; Hirsh & Peterson, 2009; Lauriola & Levin, 2001; Lönnqvist, Verkasalo, & Walkowitz, 2011; Soane & Chmiel, 2005).

In the current study, although UnU options delivered a variable reward outcome value, information concerning the value of potential losses provided a common denominator for which to compare UnO and UnU options. In this respect, observed preferences for UnU over UnO options may have reflected a trait motivated loss aversion strategy. However, neuroticism only predicted behavioural choices in the absence of external inputs. In the context of social information, behavioural preferences demonstrated a pattern consistent with adopting the perspective of others. However, this does not rule out the influence of neuroticism in predicting changes to behavioural choice preference. In the current study, the NEO-FFI measure of the ‘big-five’ is a condensed version of the NEO-PR (Costa & McCrea, 1992). Within this more detailed measure of the five domains of personality, the factor of neuroticism is constructed on the basis of six facets, two of which are impulsivity and anxiety. Given both anxiety and impulsivity are

implicated in responding to uncertain contexts (e.g. Bensi & Guisberti, 2007; Krohne & Hock, 2011; Upton, Bishra, Ahn & Stout, 2011) and social information (e.g. Butzer & Kuiper, 2006), the use of a neuroticism subscales such as anxiety and impulsivity may provide greater insight in to state versus trait aspects of choice in the context of externally provided information, and thus warrant further research.

6.5.1.2 The impact of similar others in producing preference changes

A central objective was to examine how externally provided information alters the decision context and thus behavioural choice. In this respect, social influences provided a means to achieve this. Whilst not a central argument, given that providing *any* information caused behavioural changes, it is worth acknowledging that social information carries distinctive qualities.

In the current study, in order to avoid possible confounds of advisor characteristics such as level of expertise and trust (for review see Bonaccio & Dalal, 2006), we chose to deliver social influences from similar others, i.e. participants were informed about the choices and respective outcomes made by other students who were similar to themselves.

According to social comparison theory, in the face of uncertainty, similarity with others confers a sense of prediction accuracy about what to expect (Festinger, 1954). For example, knowing another person enjoyed a particular book is uninformative, unless one is aware of instances in which both parties have agreed in the past (Suls, Martin, & Wheeler, 2002). Indeed, this form of social comparison is exploited by internet marketing strategies, that seek to influence consumer purchases through ‘similar’ others recommendations (Brown, Broderick, & Lee, 2007).

Within the context of judgement and decision research, previous studies show that even naïve advice is sufficient for revising judgements, when it is delivered by peers (e.g. Schotter, 2003; Yaniv et al., 2004), and can encourage risky behaviours in both adolescents and young adults (Andrews, Tildesley, Hops, & Li, 2002; Gardner & Steinberg, 2005).

Equally, recent findings suggest such similarity not only confers prediction accuracy in terms of what outcomes to expect, but also provide a proxy for establishing affective forecasts (Yaniv, et al., 2011). This represents a more efficient cognitive strategy that is distinct from deciding on the basis of regret from forgone opportunities (Caldwell & Burger, 2009; Kirkebøen & Teigen, 2011; Shani, Tykocinski, & Zeelenberg, 2008).

With respect to the current study findings, we suggest that similar other's experiences fill an 'informational gap' about '*if*' and '*what*' consequences will ensue, and how we expect to feel about those consequences. This perspective carries practical relevance in terms of prevention and intervention strategies that are based on the delivery of information.

6.5.1.3 Disconfirming baseline choice preferences

Although we observed that *any* type of socially provided information significantly modified behavioural preferences, this was according to whether information was either congruent or incongruent with baseline preferences. For instance, where baseline preferences favoured UnO options, social information conveying that UnO options had been previously chosen and lost, or that UnU options had been chosen and won, resulted in a preference shift towards the UnU alternative. The reverse pattern was true for participants initially favouring UnU. Whilst this may appear intuitive, appreciating the dis-confirmatory nature of information is relevant for considering *when* advice may prove beneficial.

Consistent with the notion of 'confirmatory bias', decision makers tend to give less weight to advice that contradicts their prior beliefs or opinions (Åstebro, Jeffrey, & Adomdza, 2007; Harries, Yaniv, & Harvey, 2004; Yaniv, 2004b). However, confirmatory biases are attenuated in contexts of novelty, where outcomes are less controllable and where prior attitudes and beliefs are not held with conviction (e.g. Betsch, Haberstroh, Glöckner, Haar, & Fiedler, 2001; Hart, et al., 2009). Indeed, where judgement and decision tasks prove more challenging (Gino & Moore, 2007; Gino, et al., 2009), and where decision makers lack decision-specific knowledge (Godek & Murray, 2008; Yaniv, 2004a), or confidence (Soll & Larrick, 2009), utilising advice becomes more prominent.

Whilst these findings support our hypothesis and observations concerning the use of UnU information, they do not appear, at first glance to explain why UnO information was also adopted, given our predictions.

In the current study, experience with UnO win (+170 points) and loss (-130 points) outcomes would have ensured participants could predict accurately ‘*what*’ outcomes could be expected. However, because uncertainty about such outcomes was maximal (50 % probability), participant’s *confidence* in their predictions may have been relatively low.

Whilst the acquisition of information (through either experience or advice) may improve levels of accuracy in judgements, this does not always translate to improved confidence (Fischer & Budescu, 2005). In terms of relative importance, previous studies suggest it is the level of confidence which appears critical for determining information search and acquisition (Hausmann & Läge, 2008; Lee & Cummins, 2004) and the utilisation of other’s advice (Dalal & Bonaccio, 2010; Tenney, Spellman, & MacCoun, 2008; Yaniv & Choshen-Hillel, 2011; Yaniv, Choshen-Hillel, & Milyavsky, 2009). From this perspective, it would seem reasonable to suggest that adopting other’s choices concerning UnO outcomes may have reflected a form of ‘confidence heuristic’ (Price & Stone, 2004). Critically, future examination of advice giving for UnO options derived from more definitive probabilistic schedules (e.g. 60 % win or loss) and confidence ratings would address whether this was the case.

6.5.2 ‘If’ and ‘What’ as different qualities of information

6.5.2.1 Greater relevance of acquiring information about ‘what’ over ‘if’

In addition to the dis-confirmatory impact of social influences we observed that adopting other’s choices was dependent on whether information concerned UnO or UnU options, in a manner consistent with our initial hypotheses. Specifically, whilst baseline preferences were modified by incongruent information, changes in preference were greater when incongruent information concerned UnU relative to UnO outcomes. Although it is worth noting that the interaction effect between the level of congruency

and information type only approached significance. Given the small sample size, it would be suggested that future work would seek to validate this observation using a larger sample size. Nevertheless, this differential effect between UnO and UnU information was also observed in behavioural reaction time data.

Recall that our motivations for the current study concerned the view that information about '*if*' and '*what*' reflect different qualities of information. We suggested that, where information about utility or '*what*' outcomes will occur is known, yet, there is uncertainty about '*if*' such outcomes will occur, constructing outcome expectations remains feasible. Therefore, reducing uncertainty about '*if*' may be achieved through relatively limited self-generated experience. We observed that baseline preference groups retained significantly different preferential choice patterns when exposed to UnO information, primarily because preference changes were less drastic. In this respect, it is possible that only on *some* occasions were participants responding to socially provided information, reflecting integration between prior knowledge and offered advice (Collins, et al., 2011; Soll & Larrick, 2009).

In contrast, we had predicted that where knowledge about '*what*' outcomes are variable, and less concrete, constructing an outcome expectancies would prove more challenging. We suggested that reducing such uncertainty in isolation would require extensive experience and cognitive resources. On this basis, externally provided information would be expected to carry greater utility. Indeed, our observation that both preference groups, who differ in terms of trait neuroticism, responded in the same manner to UnU information would support this view.

Behavioural reaction time data lends further support to this effect. RTs discriminated between gain and loss information, being faster for gain outcomes consistent previous accounts of gain/loss asymmetries (e.g. Della Libera & Chelazzi, 2009); however, this was only for choices informed by UnO information. Previous findings suggest faster RTs in response to reward-related stimuli reflect their preferential incentive value; however this only arises in tasks where pre-programming of a response is possible (Mir et al., 2011). The implication being that approach motivations are tied to explicit representations of incentive value.

6.5.2.2 *Relevance of information for changes in behavioural preference*

Behavioural changes in preference are an established observation (e.g. Lichtenstein & Slovic, 2006), yet, the underlying cognitive mechanisms that give rise to them remains unclear, and existing accounts vary in their conceptual basis. For example, choice-induced changes in preference are interpreted as a mechanism of dissonance reduction (Festinger, 1957) reflecting post-decision conflict. Conversely, Decision Field Theory, and similar evidence sequential sampling models (Busemeyer & Townsend, 1993; Lee & Cummins, 2004), propose theoretical accounts of preference changes as a function of information accumulation over time. Such accounts provide insight into the construction of preferences, but do not address underlying factors which bias preference.

Furthermore, preference changes place necessary question marks for both theoretical and practical accounts concerning the role of stable character traits in predicting behavioural choice. However, as previously documented, behavioural inconsistencies do not imply inconsistent strategies (Hertwig & Gigerenzer, 2011). A proposed solution is to consider behaviour as a function implemented choice heuristics within a changing environment. In this respect, the current study show how tendencies to reduce negative outcomes as a function of individual differences coincide with tendencies to reduce uncertainties as a function of the changing decision context.

6.6 Summary & Conclusion

The current study addressed two main objectives concerning the stability of behavioural preferences, and the extent to which available information about ‘if’ and ‘what’ reflect different qualities of information relevant for choice. Implementing a novel paradigm distinguishing between uncertainties about ‘if’ and ‘what’ outcomes occur, within the context of socially provided information, we demonstrated that both personality attributes and contextual factors shape behavioural choice preferences for different types of uncertainty. Our results carry several practical and theoretical implications: At a practical level, our findings correspond with previous emphasis on understanding ‘who takes risks and when’ (Figner & Weber, 2011). Furthermore, they provide a foundation for understanding the contexts in which socially provided information from similar others may prove more beneficial and is relevant for prevention/intervention

design. At a theoretical level, our findings support a view that individuals are motivated to reduce uncertainty by acquiring information; however, whilst all information is valuable, some information is more valuable than others.

In conclusion, by considering that decisions are not made in isolation, our findings provide important insights as to the nature of preference construction and change as a function of both personality and external social influences. As such, we provide important contributions towards understanding ‘who takes risks and when’ (Figner & Weber, 2011) and the role of information availability within decision making.

CHAPTER 7: General Discussion

Making decisions that have long term consequences present a challenge for a decision maker. When faced with such *intertemporal choices*, a tendency to favour options that deliver immediate outcomes can lead to suboptimal consequences in the long run. Such tendencies characterise a range of behavioural phenomena from obesity and substance use, to the excessive reliance on credit cards, and the use of environmentally harmful products and practices. Understanding the underlying processes that contribute to decision making with future consequences provides a theoretical platform for practically addressing issues of sustainable future oriented behaviour (Meijers & Stapel, 2011).

7.1 Chapter Outline

Within this thesis, the central question of how do people make decisions when the consequences of choice lie in the future was addressed by considering two fundamental aspects that characterise future outcomes: uncertainty and time.

This chapter aims to firstly summarise and then review the key experimental findings of this thesis within the context of the wider literature, including their limitations and suggested avenues for future research. This is followed by an overall critique of the approach taken, and how, collectively, the research within this thesis is situated within the current landscape of decision-making research. Finally, the thesis findings are integrated within a single theoretical framework that presents intertemporal choice as a process of decision making under uncertainty.

7.2 Overview of Thesis Findings

7.2.1 Theme 1: Delay Discounting as Uncertainty (Chapters 2 and 3)

Chapter 2 and 3 comprised experiments based on the established methodology for examining intertemporal choices. The primary objective was to examine the extent to which subjective perceptions of uncertainty and future time horizons contribute to the classically observed phenomena of DD. Chapter 2 demonstrated standard DD behaviour is driven by implicit perceptions of (un)certainty, as a function of outcome valence (gain/loss). Where delayed outcomes are gains, discount rates reflect implicit perceptions that such gains are unlikely to occur. Conversely, where delayed outcomes are losses, discount rates reflect implicit perceptions that such losses are certain to occur. Discount rate analysis based on a distinction between the EV and PCE of delayed outcomes suggested implicit perceptions of outcome uncertainty impact the representation of what reward will be received. Importantly, whilst explicitly guaranteeing the delivery of an outcome reduced discounting, this was not sufficient in abolishing discounting altogether. These results suggested uncertainty and time components within DD paradigms may contribute to distinct processes within choices between present and future outcomes. The impact of subjective time horizons was explored in more detail in Chapter 3. Modifying the way in which discount rates were derived revealed that attending to temporal features of choice produced steeper discount rates than those elicited via assessments of subjective value. Furthermore, DD rates derived from estimates of time not value were associated with self-reported concern for future consequences. Collectively results from Chapters 2 and 3 shed light on the role that implicit perceptions regarding future uncertainty and temporal horizons play within DD processing, and suggest attentional mechanisms determined by DD task variables may determine considerations of the desirability and feasibility of delayed outcomes.

7.2.2 Theme 2: Neural mechanisms of Intertemporal Choice (Chapter 4)

In Chapter 4, event-related potentials (ERPs) were used to explore the role of emotional processes in the detection and evaluation of delayed outcomes. The main findings revealed that time delays modulated both early sensory and later evaluative ERPs implicated in affective and attentional processes. These results suggest firstly that delayed rewards are less emotionally salient, showing reduced attention capture relative to immediate rewards. Secondly, that delayed rewards may be evaluated as losses. Furthermore, although response times did not determine whether immediate or delayed outcomes were obtained, reaction times were faster in response towards cues signalling immediate relative to delayed outcomes. The parallel between behavioural and ERP findings support an association between affect-related attentional bias towards immediacy and behavioural approach.

7.2.3 Theme 3: Decision Making and Uncertainty as a Proxy for Intertemporal Choice (Chapters 5 and 6)

Chapters 5 and 6 comprised experiments in which uncertainty about ‘*what*’ outcomes may occur was operationalised as uncertainty in outcome utility (UnU). A shared objective of both chapters was to demonstrate how UnU and uncertainty in outcome likelihood (UnO), or ‘*if*’ represent distinct sources of outcome uncertainty. In Chapter 5 this distinction was addressed using both an individual differences approach and behavioural tasks that are traditionally employed as measures of risky and impulsive choice. The major output of these efforts demonstrated UnU aligns with ‘impulsive’ choice and may therefore provide a proxy for considering the uncertainty associated with delayed outcomes. In Chapter 6, this distinction was extended by adopting a social influence perspective and addressing the stability of behavioural choice preferences. In this case, a distinction between UnO and UnU was established in terms of their differential qualities as sources of information based on behavioural preference changes and reaction time data.

7.3 Integration of thesis findings within the wider decision literature

Given the diversity of methodological and conceptual approaches employed, the results reported offer several contributions within subfields of decision making. For instance, Chapters 2 and 3 evoke important issues for the conduction of delay discounting studies, whereas Chapters 5 and 6 present novel contributions for understanding the varieties of uncertainty that arise within decisions. Equally, the novel employment of electrophysiological methods for investigating delayed outcomes in Chapter 4 hold important implications for the neural investigation of intertemporal choice.

7.3.1 Theme 1: Delay Discounting as Uncertainty (Chapters 2 and 3)

As described in Chapter 1, DD represents the prototypical model for intertemporal choice and provided the starting point for this thesis. As such, a primary objective was to examine the extent to which DD represents a consequence of uncertainty. Although there have been several attempts to address this question, the methodologies described in Chapters 2 and 3 suggest a novel and more robust approach. For example, previous attempts involved correlating delay and probability discounting (e.g. Estle, et al., 2006; Myerson, et al., 2003), or converting probabilities into equivalent delays (Yi, et al., 2006). These approaches operate under the assumption that increasing time delays map directly to decreasing probabilities, and raise two important concerns. First, positive (albeit weak) correlations between delay and probability discounting are counterintuitive if impulsivity is conceptualised as a preference for immediacy (steeper delay discounting) and a propensity to take risks (shallower probability discounting) (Myerson, et al., 2003). Second, such approaches only imply that a single discounting process underlies the evaluation of delayed and probabilistic outcomes. They do not however, address the nature of the relationship between time and uncertainty, i.e. how and in what way is the future inherently uncertain?

Chapters 2 and 3 addressed these questions directly, revealing implicit perceptions of the future are far from objective. These results suggest time delays invoke uncertainties about *if* and *when* outcomes will occur. In turn, *if* and *when* considerations impact the representation of *what* outcomes lie in the future, via different cognitive and affective

processes; however, crucially, the predominance of *if* and *when*, depend upon the mode in which choices are evaluated. The primary significance of this perspective has been to provide a foundation for the remainder of the work presented in this thesis. Within this discussion, I shall focus on how these findings relate to wider DD literature.

7.3.1.1 Contributions for Delay Discounting Research

Taken as a whole, the findings from Chapters 2 and 3 carry several methodological and conceptual implications for understanding why we discount the future, and are summarised in Figure 7.1. Methodologically, the findings highlight the relevance of evaluation mode and attentional focus when assessing DD. Conceptually the findings are relevant for considering the cognitive and affective contributions in the construction of subjective value.

7.3.1.2 Methodological Contributions: Evaluation mode and attentional focus

An important critique of DD approaches is their assumption that outcomes and delays are perceived objectively and in isolation (Frederick, et al., 2002; Soman, et al., 2005). Making erroneous assumptions about how participants consider DD choices ultimately influences how we calculate and interpret discount rates. This begs the question as to how valid DD is as a behavioural model of impulsive choice.

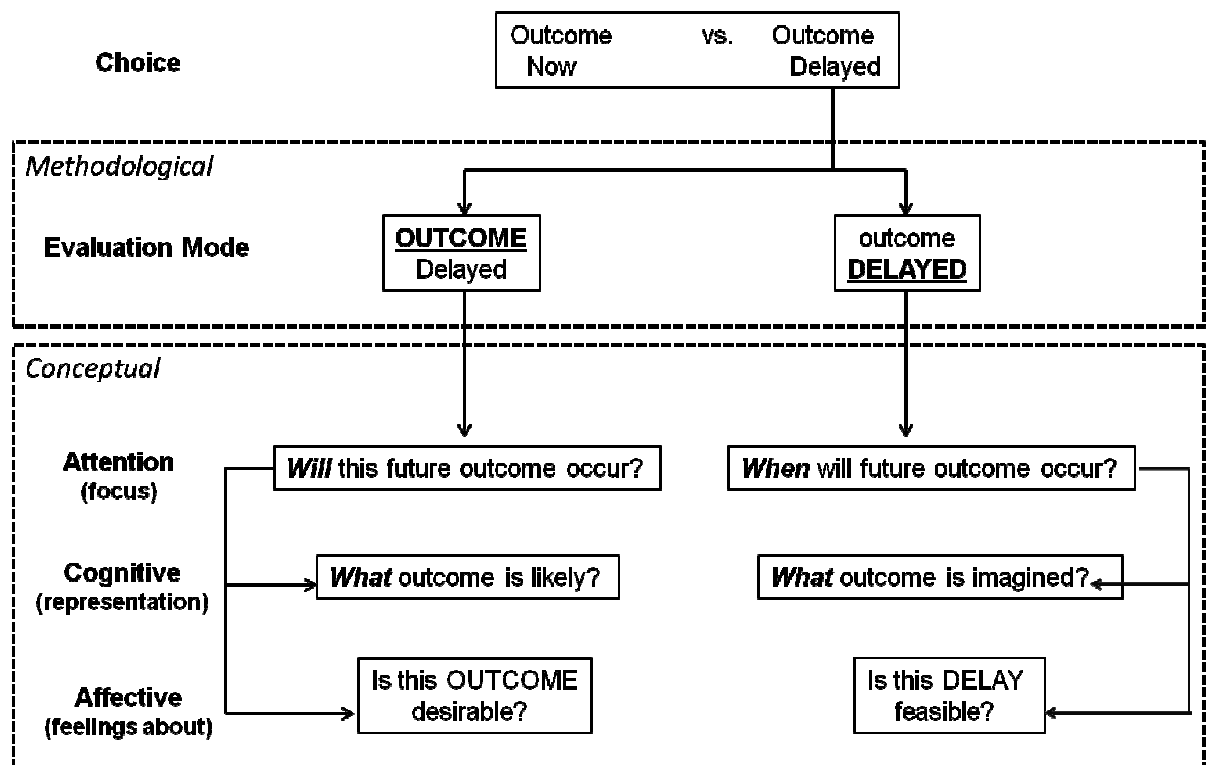


Figure 7.1. Outline of methodological and conceptual contributions of Chapter 2 and 3.

Such a question is problematic given the widespread use of the DD framework in both decision research and clinical domains. And yet, to suggest an overhaul of the DD framework would be an exemplar of an impulsive response. For example, drawing an analogy with the Iowa Gambling Task (IGT), like DD, the IGT is widely used in both decision research and clinical settings. However, several studies have questioned its validity as a measure of myopic decision making (Brand, et al., 2007; Buelow & Suhr, 2009; Colombetti, 2008; Dunn, Dalgleish, & Lawrence, 2006; Gansler, Jerram, Vannorsdall, & Schretlen, 2011; Lin, Chiu, Lee, & Hsieh, 2007; Suhr & Hammers, 2010). Nevertheless, these very critiques have contributed to an appreciation of attentional and executive processes involved in decision making. Therefore, despite the methodological issues associated with DD that are described within this thesis and by others (e.g. Fellows & Farah, 2005; Smith & Hantula, 2008), it is these methodological problems which make the DD paradigm useful, providing some caveats.

Distinguishing between descriptive and experiential modes of decision making under uncertainty has afforded several noteworthy advances (e.g. Camilleri & Newell, 2011). However, for decisions with delayed outcomes, such a distinction cannot be meaningfully addressed in real time (indeed, studies would be hard pressed to recruit and reimburse participants with durations of 5, 10 or 25 years!), although attempts have been made (Reynolds & Schiffbauer, 2004; Schweighofer, et al., 2006; Wittmann, Lovero, Lane, & Paulus, 2010). Therefore, the descriptive approach provides the only useful and feasible means to address choices involving present and future consequences. That is not to say the manner in which such choices are presented cannot be improved.

Given that both DD-A and DD-T tasks evoked different evaluation modes, and invited different perspectives of DD, I would suggest there is much to be gained from incorporating both procedural variants within DD research. For instance, although there is evidence to support a trait-based view of DD, this view is hindered by inconsistencies between DD and self-reported impulsivity (e.g. Bobova, Finn, Rickert, & Lucas, 2009; Dom, De Wilde, Hulstijn, & Sabbe, 2007; Janis & Nock, 2009; Perales, Verdejo-Garcia, Moya, Lozano, & Perez-Garcia, 2009). Such inconsistencies are reconciled by taking into account the heterogeneous nature of impulsivity (Congdon & Canli, 2005; Evenden, 1999), or the limitations of self-report measures (Wilson & Dunn, 2004). However, Chapter 3 revealed a closer relationship between self-reported concern for future consequences and discounting under DD-T but not DD-A. This suggests the traditionally used DD-A format may underestimate the impact of waiting durations. Exploiting both DD-A and DD-T tasks within, for example impulsive populations, could potentially distinguish between types of behavioural impulsivity.

Another potential contribution concerns non-monetary discounting. It has been recently pointed out that monetary rewards constitute an unnatural reward for DD studies (Huettel, 2010). Alternatively, non-monetary rewards represent a more appropriate model for an evolutionary conserved and therefore general framework, of discounting processes. To this effect, various studies have examined the discounting of non-monetary outcomes such as future medical treatment and health (Chapman, 1996; Chapman, et al., 2001), environmental outcomes (Hardisty & Weber, 2009), body image (Weatherly, Terrell, & Derenne, 2010), legislation (Weatherly, Derenne, &

Terrell, 2011), foods and beverages (Estle, et al., 2007; Odum, et al., 2006; Odum & Rainaud, 2003) and more materialistic items such as books and CDs (Charlton & Fantino, 2008). However, measuring discounting across commodities represents a methodological challenge; how does one calculate a discount rate for a commodity that has no discernible unitary scale? In the above examples, this issue has been overcome by assigning monetary values to abstract delayed outcomes. For example, in the case of food discounting, the objective value of a preferred food such as pizza, is calculated according to its unit cost, e.g. \$3.00 apiece. To correspond with a monetary DD task, e.g. \$100 in 1 month, the delayed food reward is presented as 33.3 pieces of pizza in 1 month (Odum, et al., 2006). Similarly, choices concerning future environmental outcomes such as air quality are presented as a choice between gaining \$250 today or improved air quality in 1 year for 35 days (Hardisty & Weber, 2009). Such choices are not only far from realistic, but also confound objective amounts and value. In this respect, the DD-T task may provide a more appropriate method, particularly as it allows for the comparisons between incommensurable outcomes, e.g. would you prefer an apple now or a pizza in 2 hours?

7.3.1.3 Conceptual Contributions: cognitive and affective contributions

As previously described, various accounts have been posed to explain why the future is discounted. For example, in addition to the consideration that the future is uncertain, others have considered discounting to be a function of temporal construal (Trope & Liberman, 2003) emotional intangibility (Rick & Loewenstein, 2008), metabolic and visceral urges (Charlton & Fantino, 2008; Wang & Dvorak, 2010) or even the manifestation of a trait variable (Odum, 2011). Furthermore, findings implicating individual differences in intelligence, working memory and executive functions (Bickel, Yi, Landes, Hill, & Baxter, 2011; de Wit, et al., 2007; Hinson, et al., 2003; Olson, et al., 2007; Shamosh, et al., 2008), as well as motivational tendencies such as neuroticism and extraversion (Hirsh, et al., 2010; Hirsh & Peterson, 2009). Collectively, this work presents a complex picture that on the surface appears incompatible with a single unified theory.

In this respect, perhaps the most significant contribution offered by the studies in Chapters 2 and 3 lie in their ability to integrate such diverse views within a general account. For instance, the mode in which delayed outcomes are evaluated will determine the allocation of attention (e.g. Armel, Beaumel, & Rangel, 2008; Schmeltzer, Caverni, & Warglien, 2004; Weber & Johnson, 2009). Where attention is drawn to the delayed outcome itself, subjective perceptions of likelihood come in to play and affect the representation of *what* outcome may be expected. Cognitive abilities implicated in judgements about uncertain outcomes (e.g. Del Missier, Mäntylä, & de Bruin, 2011; Weaver & Stewart, 2011) such as working memory, intelligence, and numeracy, may contribute towards constructing representations of ‘*what*’ will occur in the future. Equally, attending to the likelihood of a delayed outcome may trigger anticipated affective responses such as dread, regret or curiosity (e.g. Harris, 2010; Kobbeltvedt & Wolff, 2009; van Dijk & Zeelenberg, 2007).

Where attention is drawn towards the temporal features of a delayed outcome, subjective temporal horizons may also impact representations of *what* outcomes are to be expected. For instance, distant outcomes are represented more abstractly than proximal outcomes (Trope & Liberman, 2003). However, ensuing cognitive and affective processes may differ from those initiated by concerns over likelihood. For example, contemplating temporal durations may rely on cognitive abilities of prospective thought such as planning, episodic memory and past recall (e.g. D’Argembeau & Van der Linden, 2006; Gamboz, Brandimonte, & De Vito, 2010; Schacter, Addis, & Buckner, 2007). Similarly, attending to durations may stimulate immediate emotions such as frustration and anger (Voorhees, Baker, Bourdeau, Brocato, & Cronin, 2009), as well as anticipatory responses that are more visceral in nature (Loewenstein, 1996).

Notably, the above distinctions are not mutually exclusive. Rather, my intent here is to show that implicit perceptions of uncertainty and temporal horizon create, albeit in different ways, variability in *what* outcomes may be expected. In this way, consistent with more recent perspectives (Epper, et al., 2011), a parallel may be drawn between DD and decision making under uncertainty, and provides a framework that subsequent sections in this thesis will develop.

7.3.1.4 Limitations and Future Research

A critical limitation made by both chapters is the assumed the role of attentional focus. However, it is one that is made by commonly by both DD studies (e.g. Bickel, et al., 2011; Read, et al., 2005) and behavioural studies of choice in general. Nevertheless, as shown in Chapter 4, using alternative methodologies such as EEG, which are particularly well suited for investigating attentional processes, exploring the assumptions detailed here may benefit from exploiting these techniques.

A second limitation which is more easily remedied concerns the lack of any measures to control for cognitive load. For example, whilst acknowledging the FITB method used in Chapter 3 is a more effortful and cognitively demanding procedure (Smith & Hantula, 2008), I did consider the extent to which enhanced myopia for the future found for the DD-T procedure presented as a function of cognitive load. Estimating time intervals is perhaps more cognitively demanding than estimating amounts, and yet, as discussed in Chapter 3, perhaps a more realistic perspective of everyday ITCs (it is more common to think about how long one has to wait, than think about the current value of a delayed event). Nevertheless, employing an adjustment/titration procedure within the context of a DD-T design would address the extent to which cognitive load per se and/or subjective time perceptions are responsible for steeper discounting under DD-T tasks. Furthermore, the use of iterative adjustment tasks would also enable extrapolation to the standard procedures used in the remaining DD studies within this thesis. However, in this respect, it is also worth noting that the adjustment/iterative procedures like that employed in Chapter 2 suffer from a similar cognitive load critique; in this case, working memory function (e.g. Hinson, et al., 2003). Given the emphasis I have placed on cognitive processes such as attention and working memory in the current studies, a possible solution would be to control for individual difference variables such as working memory, and other executive function abilities.

7.3.2 Theme 2: The Neural Basis for Intertemporal Choice (Chapter 4)

Chapter 4 described a novel paradigm comprising of electrophysiological techniques and a non-choice task design to isolate the effect of delay on reward detection and evaluation. The primary out-put of this approach presented an emotion-orientated perspective of delayed reward processing. Here I shall discuss the implications of this work within the context of the aims of this thesis and the recent literatures concerning self-control and selective attention.

7.3.2.1 Links to thesis aims:

7.3.2.1.1 Common neural signatures between decision making under uncertainty and intertemporal choice

From Chapter 1, it is clear that when this thesis was commenced, attempts to explicitly address a common valuation system between intertemporal choice and decision making under uncertainty within humans was lacking. Whilst this is no longer the case, current fMRI attempts have, nonetheless, produced mixed findings (e.g. Luhmann, Chun, Yi, Lee, & Wang, 2008; Peters & Buchel, 2009; Weber & Huettel, 2008), and mirror those made by behavioural studies and have been discussed in section 7.1.1. As an alternative approach, I considered the fRN component observed in electrophysiological studies of feedback guided decision-making (refer to Chapter 4).

The involvement of the fRN component in assigning outcomes with motivational relevance has been well characterised within the context of decision making under uncertainty (e.g. Bellebaum, et al., 2010; Hajcak, et al., 2006; Hajcak, et al., 2007; Hewig, et al., 2008; Holroyd, Hajcak, & Larsen, 2006; San Martín, Manes, Hurtado, Isla, & Ibañez, 2010). The observation that the fRN is similarly modulated by delay is relevant not only for drawing a methodological parallel between decisions involving time and uncertainty, but also for elucidating common neural and cognitive processes.

For example, although the precise functional significance of the fRN remains debated (see Cohen, Wilmes, & van de Vijver, 2011), a predominant model of fRN function is based upon dopaminergic neurons signalling changes in the motivational status of predicted reward outcomes (Holroyd & Coles, 2002; Holroyd & Coles, 2008; Marco-

Pallares, et al., 2009; Santesso, et al., 2009). From this perspective, the delay-related modulation of the fRN would suggest dopamine neurons are also sensitive to the impact of delay on reward value.

Dopaminergic functioning is well documented within general accounts of reward processing (Berridge & Robinson, 1998; Schultz, 1997; Wise & Bozarth, 1981; Wise & Rompre, 1989), in the coding of reward uncertainty (Fiorillo, et al., 2003; Schultz, 2006), decision making under contexts of risk (Schultz, 2010; St Onge & Floresco, 2009; Zhong, et al., 2009), and in models of interval time perception (e.g. Meck, 1996; Wittmann, et al., 2007). However, in terms of delayed reward processing, supporting evidence has been derived from either populations characterised by dopaminergic-irregularities (e.g. substance users, and ADHD), or animal studies (e.g. Kobayashi & Schultz, 2008). The implication that dopamine is also sensitive to delayed outcome status parallels more recent DD findings within humans using pharmacological dopaminergic manipulations (Housden, O'Sullivan, Joyce, Lees, & Roiser, 2010; Paloyelis, Asherson, Mehta, Faraone, & Kuntsi, 2010; Pine, Shiner, Seymour, & Dolan, 2010), and neuro-genetic techniques (Carpenter, Garcia, & Lum, 2011).

7.3.2.1.2 Attention & Emotion

A corollary of implicating dopamine in delayed reward processing is that delayed rewards are also ascribed with reduced incentive salience (Berridge, 2007; Berridge & Robinson, 1998; Schultz, 1997). Indeed, as reported in Chapter 4, stimuli signalling delayed rewards modulated early sensory-related ERP components that index selective visual attention and affective processing; i.e. delayed rewards are less emotionally salient, and show reduced attention capture. These observations are consistent with the framework linking reward and emotion (Rolls, 1999), and provide a conceptual parallel between time and uncertainty.

According to models such as 'risk as feeling' (Loewenstein, et al., 2001), and the 'affect heuristic' (Finucane, et al., 2000; Slovic, Finucane, Peters, & MacGregor, 2002), contexts of decision uncertainty induce affective responses at the point of choice, and serve as important decision inputs (Mellers & Schwartz, 1997; Pham, 2007; Schwarz & Clore, 1988; Slovic, et al., 2002). Indeed, following the work of somatic markers, i.e.

the physiological manifestation of emotions (Bechara & Damasio, 2002; Bechara, Damasio, Damasio, & Lee, 1999; Damasio, 1996), a wealth of studies have empirically demonstrated the importance of affective responses in guiding decisions that involve uncertainty (e.g. Coricelli & Rustichini, 2009; Luhmann, Ishida, & Hajcak, 2011; Mikels, Maglio, Reed, & Kaplowitz, 2011; Stocco & Fum, 2008) as well as their neural correlates (e.g. Litt, Eliasmith, & Thagard, 2008; Naqvi, Shiv, & Bechara, 2006; Rolls & Grabenhorst, 2008; Shiv, Loewenstein, & Bechara, 2005; Weller, Levin, Shiv, & Bechara, 2007).

The extent to which emotional reactions are generated is determined by the vividness with which potential outcomes are represented (Damasio, 1994). Given that temporal distance impacts the degree to which future outcomes are represented (Lieberman, Sagristano, & Trope, 2002; Trope & Liberman, 2003), a similar argument has been made for intertemporal choice, in that immediately experienced emotions serve as a proxy for delayed and ‘intangible’ rewards (Rick & Loewenstein, 2008). However, unlike the case of decision uncertainty, supporting evidence for the role of experienced emotions with delayed outcome choices has until recently, been less than clear on this issue (refer to Chapter 4 for details). Although my task paradigm was not a true reflection of choice, the implication that experienced emotions are involved in delayed reward processing is consistent with more recent behavioural DD studies have begun to embrace this concept (Harris, 2010; Hirsh, et al., 2010; Walther, 2010), and supports my previous arguments that DD reflects the impact of implicit, and therefore, automatic processes (Section 7.1.1.).

7.3.2.2 Links to wider neuroscience literature

Whilst the approach described in Chapter 4 represents a departure from the traditional DD format employed by earlier fMRI studies, the novel task design is consistent with recent accounts of the neurobiology of self-control and reward-guided selective attention.

As outlined in Chapter 1, earlier neurobiological studies of intertemporal choice focused on relationships between neural activity and behavioural models of discounting. Such model based accounts have encouraged a debate between single versus multiple

valuation systems, which continues to dominate neural accounts of DD (e.g. Carter, Meyer, & Huettel, 2010; Luhmann, 2009; Monterosso & Luo, 2010; Peters & Büchel, 2011; Sellitto, Ciaramelli, & di Pellegrino, 2011; Wittmann & Paulus, 2009a). However, this approach has proved limiting (Huettel, 2010), primarily because such approaches are not informative for understanding how time impacts reward value and the mechanisms that enable future sighted behaviour, i.e. self-control.

As a response to these limitations, more recent fMRI studies have implemented more elegant designs that focus on specific aspects of intertemporal choice, rather than the process as a whole (Ballard & Knutson, 2009; Luo, Ainslie, Giragosian, & Monterosso, 2009; Peters & Büchel, 2010). The culmination of this shift away from an explicit and purely descriptive DD format is evidenced by more recent neurobiological accounts of self-control processes (Figner, et al., 2010; Hare, Camerer, & Rangel, 2009; Hare, Malmaud, & Rangel, 2011). These approaches have placed a central emphasis on the role of ‘top-down’ mechanisms of attentional selection in the construction of value in guiding choices which have future consequences.

Conversely, recent electrophysiological studies concerned with models of selective attention have focused on the endogenous properties of reward in guiding ‘bottom-up’ mechanisms of selective attention capture (Nummenmaa, et al., 2011; Piech, Pastorino, & Zald, 2010; Werthmann, et al., 2011). Consistent with models of ‘incentive salience’ (Berridge & Robinson, 1998), behavioural and ERP studies have shown that monetary rewards (Della Libera & Chelazzi, 2006, 2009; Hickey, et al., 2010a), emotional faces (Shimojo, Simion, Shimojo, & Scheier, 2003) as well as arbitrary stimuli imbued with value via associative learning (Anderson, et al., 2011) capture attention automatically and bias subsequent behaviour. Furthermore, such value driven attention capture has been shown to co-vary with individual differences in impulsivity (Anderson, et al., 2011) and reward sensitivity (Hickey, et al., 2010b), and directly implicates dopaminergic function in attentional control (Hickey, et al., 2010a).

Inevitably however, understanding how attentional control operates, particularly within contexts where multiple choice options both vary and compete for attentional resources requires integrating both top-down and bottom-up approaches, which continues to be a source of both debate and inspiration across studies (for reviews see Corbetta & Shulman, 2002; Pessoa & Engelmann, 2010; Theeuwes, 2010). The implications of such an integration for decision making at both a behavioural and neural level however will be invaluable as attentional processes present as an intersection emotion and cognition (Ochsner & Gross, 2005; Ochsner, et al., 2009; Pessoa, 2008). To this end, it is worth considering the approach reported in Chapter 4 represents a convergence point between the fMRI studies of intertemporal choice in terms of the underlying conceptual basis, and the behavioural-ERP studies of selective visual attention, in terms of the methodological approach.

7.3.2.3 Limitations & Future Work

Although Chapter 4 presents a novel approach towards understanding neural markers of intertemporal choice, an obvious limitation was the clear absence of an explicit choice context. However, given the novel employment of EEG to address intertemporal processes, this was a necessary compromise that allowed me to establish whether and how ERP correlates respond to delayed outcomes. A notable extension of the current findings would be their application within an explicit choice design. Secondly, it is worth considering that despite the implication for impulsive choice, the current EEG study was conducted within a sample of healthy under-graduate students and did not take into account individual differences previously shown to modulate the ERP components of interest (Lange, Leue, & Beauducel, 2012; Potts, 2011; Santesso, et al., 2011; Smillie, Cooper, & Pickering, 2010). Therefore, two plausible extensions would be to explore whether observed ERP modulations are a function of individual differences in both impulsive and emotional reactivity/regulation tendencies, and their characterisation within designated ‘impulsive’ populations (e.g. Fein & Chang, 2008; Kamarajan, et al., 2010; Luijten, van Meel, & Franken, 2011). Equally, implicating attentional focus in driving neural and behavioural responses towards delays naturally invites a number of possibilities for future investigations; for example, the extent to which neural markers of delayed outcome processing reflect stable or changeable

responses, and whether they may be useful for identifying instances of behavioural change. Such questions could be appropriately investigated by adapting behavioural paradigms to include either an intervention component, or test-retest validity in conjunction with neural methods, either EEG or fMRI, to examine possible changes in neural response activity over time.

7.3.3 Theme 3: Decision Making Under Uncertainty as a Proxy for Intertemporal Choice (Chapters 5 & 6)

Collectively, Chapters 5 and 6 present a view of decision-making under uncertainty as a dynamic process of information optimisation, acquisition and utilisation. Importantly, where complete information about ‘*if*’ and ‘*what*’ is unknown, decision-making depends upon an interaction between the internal (e.g. individual trait characteristics) and external (choice context) decision environments. By conceptualising delayed outcomes as a source of missing information concerning ‘*what*’, this framework has the potential for addressing both risky and intertemporal decisions, and is addressed in more detail in section 7.11.

Whilst the motivation for exploring the concept of ‘*what*’ uncertainty emerged from considering intertemporal choice as a function of uncertainty, this was achieved by integrating several different questions with decision research. For example, the role of behavioural approach motivations within ‘risky’ choice, the stability of behavioural preferences, and the impact of social influences. In this respect, the distinction between ‘*if*’ and ‘*what*’ offers a novel perspective for addressing key issues within both judgement and decision making (JDM) and clinical-related areas of decision research.

7.3.3.1 Bridging conceptual gaps: different conceptions of ‘risky’ choice

A key contribution made by distinguishing between UnO and UnU lies in the ability to address a conceptual gap of what is meant by ‘risk’ between two key domains of decision research: economic driven judgement & decision making (JDM) and clinically-related decision making (CDM).

Despite their shared use of the terms ‘risk’, defining risk and risky taking behaviour varies considerably. For instance, within the JDM literature, as risk is defined by its statistical nature risk-seeking is viewed as a preference for higher variance pay-offs (e.g. probabilistic), holding expected value constant⁴. In contrast, a CDM perspective of risk-taking is based on specific behaviours that have the potential for negative or harmful outcomes, such as drug use, unprotected sex, and mountain climbing (Steinberg, 2008). And yet, lay conceptions of riskiness distinguish between dimensions of ‘dread’, characterised by lack of control and/or potential catastrophic consequences, and the ‘unknown’, characterised by unobservable, unfamiliar, and/or delayed consequences (Paul Slovic, Fischhoff, & Lichtenstein, 1984).

Whilst the need for a common conception of risk and risk-taking has been emphasised (Schonberg, Fox, & Poldrack, 2011), how this is meant to be achieved has not been explicitly addressed. My distinction between ‘*if*’ and ‘*what*’ as uncertainties in outcome occurrence and utility provide a bridge for these conceptual differences.

Whilst utility theories only explain how utilities are used to make choices, the utilities themselves are left unexplained. Isolating and dissociating between dimensions of outcome variability demonstrates how they separately contribute to quite complex behaviour. This parallels current perspectives in decision neuroscience research (Huettel, 2010), approaches based on Bayesian inference (Landy, Goutcher, Trommershäuser, & Mamassian, 2007; Trommershäuser, Maloney, & Landy, 2008; Wu, Delgado, & Maloney, 2009) and recent efforts to deconstruct risk in terms of outcome “summary statistics” (Symmonds, Wright, Bach, & Dolan, 2011).

7.3.3.2 Choosing methods for risky choice

The bridge between conceptual notions of risk was made possible by a critical design feature that is generally overlooked by both JDM and CDM research; the use of predefined correct and optimal strategies. For example, within CDM behavioural tasks

⁴ Although, in a number of studies, the risky option is also higher in terms of its expected value (see Hertwig et al., 2004).

such as the IGT, ‘playing it safe’ is deemed as the correct and optimal strategy which produces greater gains for the decision maker. Conversely, choosing to take risk results in losses and is viewed as ‘dysfunctional’; this is ironic, given that, within economic and JDM frameworks, risky choice presents as the optimal solution, such that choosing to play it safe is evidence of irrationality. Clearly confounding uncertainty with utilitarian and performance indices within behavioural tasks creates confusion for interpreting behavioural responses.

This does not imply that such dimensions are not important features of decisions with uncertainty. Indeed, comparing Chapters 5 and 6 emphasises the impact that tangible losses play in modifying behavioural preferences for different uncertainties. Compared to the cognitive costs carried by missing information within a gain only context, the presence of tangible costs may dominate choice.

7.3.3.3 Individual differences

Understanding characteristics of the individual which influence decision behaviour inevitably carries a number of implications beyond the ‘laboratory’; for example, in the design of therapeutic interventions strategies (e.g. Jackson, Geddes, Haw, & Frank, 2011). However, the challenge for decision research lies not in identifying what individual differences are implicated, rather, what aspects of the decision process do such characteristics impact.

Within a JDM framework, individual difference approaches tend to focus on cognitive characteristics such as consistency, inhibition, cognitive reflection and executive functioning which support adaptive responses to contextual changes (e.g. Del Missier, Mäntylä, & Bruine de Bruin, 2010; Liberali, Reyna, Furlan, Stein, & Pardo, 2011).

Alternatively, within CDM frameworks, individual differences are construed as stable enduring responses towards the balance of potential gains and losses (e.g. Luce, 2011; Mishra & Lalumière, 2011; Pothos, Perry, Corr, Matthew, & Busemeyer, 2011; Skatova & Ferguson, 2011; Studer & Clark, 2011). Such individual differences may reflect variation in underlying personality (e.g. Mishra & Lalumière, 2011) or affective dimensions, such as mood state (for an overview see Weber & Johnson). Notably, the

studies reported in the current thesis have only attempted to address the former source of individual variation in personality substrates (see section 7.3.3.4)

Intuitively, decision making reflects the contribution of both personality and contextual factors, and has become a shared central objective within both JDM and CDM domains (Appelt, Milch, Handgraaf, & Weber, 2011; Borghans, Golsteyn, Heckman, & Humphries, 2011; Ferguson, et al., 2011). However, there is currently no parsimonious account for integrating these two dimensions of choice.

In Chapter 6 we demonstrated that asking the right questions on the basis of a strong theoretical rationale, provided a methodological design in which both personality and contextual variables were both compatible and necessary components.

7.3.3.4 Limitations & Future work

Whilst the operationalisation of ‘*what*’ as uncertainty in outcome utility is a novel aspect within behavioural decision making, its characterisation is not without limitations. For instance, in both Chapters 5 and 6, UnU options were constructed on the basis of a relatively large (nine) possible outcome amount values⁵. Adopting similar perspectives to that of relative judgement (Stewart, Chater, & Brown, 2006), I assumed a larger distribution of outcome possibilities necessarily demands additional cognitive resources e.g. working memory capacity. However, despite equating UnO and UnU in terms of expected value, differences in terms of variance were not accounted for. Therefore, fully characterising the features of UnU, and hence ‘*what*’ are potential avenues for further investigation. This may be in the form of behavioural studies that explore properties of a variable sample distribution, for example, the variance and number of options per se within a sample. Equally, the application of neural methods such as EEG or fMRI could aid a distinction between UnO and UnU in terms of neural systems which support the perception and evaluation of these options.

⁵ This figure was derived from numerous piloting of the experimental paradigm, and not chosen arbitrarily.

A second methodological issue worth noting is the manner in which choice behaviour was analysed. Across both chapters, participants' averaged behavioural choice provided the dependent variable. This simplified approach, which assumes stability over trials, was chosen given both the conceptual and methodological novelty of the paradigm. This limits the conclusions that could be drawn about how choice preferences for UnO and UnU develop over time and with experience. Future work should consider the dynamics of preference formation through information acquisition and experience, including how UnO and UnU components might differ in shaping these dynamics.

Further, it is also unclear whether or how UnO and UnU differ in terms of outcome expectancies. The EEG paradigm in Chapter 4 offers an objective approach to test this while avoiding interference from introspection. Relatedly, alternative sources of individual differences, namely affective dimensions such as individual's mood state could prove useful. For instance, mood states such as anger and happiness are associated with certainty appraisals (i.e. the extent to which an individual understands and can predict what will happen). Alternative mood states such as fear are associated with uncertainty appraisals, such states impact cognitive processes involved in judgements and decision making, for example, anger and happiness moods are associated with reduced risk taking, whereas fear leads to higher rates of risk taking (e.g. Bagneux, Bollon & Dantzer, 2011; Lerner & Keltner, 2000). Priming mood states prior to engagement in UnO-UnU based decisions could test the hypothesis that these uncertainties reflect different cognitive process.

A source of motivation for the current thesis was the issue of incentive-based interventions for long term behaviour change. Chapters 5 and 6 show that the decision environments within which incentives operate comprises different types of uncertainties. Furthermore, both trait factors and the social environment are central influences for determining how individuals respond and manage such uncertainties. A natural progression of these findings would be to examine their application for behavioural change within an ecological setting.

In that respect, a limitation of not only Chapter 5 and 6 but one of all the works presented in this thesis is the issue of generalisability. The samples of participants used across all studies were predominantly students or affiliated members of the University of Manchester. As most of the studies reported involve the development of novel methodologies, the use of such homogenous samples is perhaps justified. However, it goes without saying that in order to substantiate the current results, all studies would greatly benefit from incorporating more heterogeneous samples: for example, the inclusion of alternative age groups could shed light on distinctions between UnO and UnU cognitions. Adolescents are consistently reported to show greater engagement in risky choices, particularly choices which have long term negative consequences. In this respect it would be of interest to see whether such age groups showed a heightened preference for UnU options relative to older adults. Similarly the paradigms developed in chapters 4, 5 and 6 replicated in populations characterised by high impulsivity (e.g. smokers, substance users etc) would also provide tests of generalizability and validity to the current findings. For example, it would be expected that individuals characterised by high impulsivity would evidence greater modulations in the ERP indices as a function of delay as described in Chapter 4. Also, such individuals, who have been previously reported to show steeper rates of discounting, would also be expected to demonstrate greater aversion to the presence of UnU options (relative to safe alternatives).

7.4 Critical Assumptions: Choice as a reflection of Preference?

Taken as a whole, the variety of methods and perspectives that have been used to address human choice and preference provide an integrative view of decision making of the kind that is very much still needed (Huettel, 2010; Lebiere & Anderson, 2011). Nevertheless, it is necessary to reflect on one core assumption that has been made. Throughout this thesis I have operated under the assumption that the choices made by participants are truly reflective of their hedonic preferences. This assumption is partly reflective of my background in neuroscience and the traditional neuroeconomic approach I began with when this current work was commenced. Both economic and neuroscience traditions share a perspective that motivated behaviour provides all the necessary information about utility, as people are motivated to their optimise hedonic experience. Therefore, in the absence of any constraints, preference and choice will

coincide (Rolls, 1999). And yet, psychologists have long argued that preferences are transitive, reflecting the construction of utilities as the situation arises (Kahneman & Snell, 1992; Lichtenstein & Slovic, 2006; Shafir, Simonson, & Tversky, 1993). This view derives from an appreciation that cognitive processes such as perception, memory and attention reflect the integration between properties of the environment and an information processing system that is limited in capacity.

This perspective has received increasing support from studies illustrating how actions can create as well reveal preferences (Ariely & Norton, 2008; K. W. Chapman, Grace-Martin, & Lawless, 2006; Coppin, Delplanque, Cayeux, Porcherot, & Sander, 2010; Sharot, Riccardi, Raio, & Phelps, 2007; Sharot, Velasquez, & Dolan, 2010; Stewart, 2009; Ungemach, Stewart, & Reimers, 2011). Indeed, recognising the role played by contextual factors was central to the design and interpretation of the studies reported in Chapters 2, 3, and 6.

However, if behavioural choices do not provide a valid assessment of subjective hedonic experience, or reflect an individual's true preference, does this influence the way in which decision research should be conducted? Some have argued only neuroscience techniques will shed light on this issue (Ariely & Norton, 2008). For instance, recent fMRI studies have revealed patterns of neural activity that distinguish reward value from hedonic experience (McClure, Li, et al., 2004; Plassmann, O'Doherty, Shiv, & Rangel, 2008; Small, et al., 2007); similarly, TMS approaches can manipulate neural activity directly to effect behavioural change (Figner, et al., 2010; Wout, Kahn, Sanfey, & Aleman, 2005). However, the issue of inferred choice remains contentious.

As such, the assumption of inferred preference and its relationship with behavioural choice is one not limited to this body of work alone, but is one that is currently faced by decision scientists as a whole (Kusev & Van Schaik, 2011; Villejoubert & Vallée-Tourangeau, 2011).

7.5 Theoretical Framework: ‘if’ ‘what’ and ‘when’ as a model of Information Availability

The current thesis demonstrates how a more in-depth perspective of human choice can be afforded by integrating a variety of conceptual and methodological approaches. The efforts of this integration are embodied in the development of an ‘Information Availability’ framework that collectively captures the major thesis findings. This is summarised in Figure 7.2.

An important feature of this model is that no component acts in isolation, or takes precedence. The reciprocal associations between components are a defining feature of the model which makes it adept for modelling dynamic decision behaviour.

Within this account, risky and impulsive decisions can be distinguished in terms of the information that is both available and missing, i.e. information about ‘if’ and ‘what’ outcomes will occur respectively. These types of information appeal to different underlying traits which inform behavioural strategies to seek out additional information (through either direct experience or from social sources), and drive different emotional responses which serve as proxies for information that is lacking.

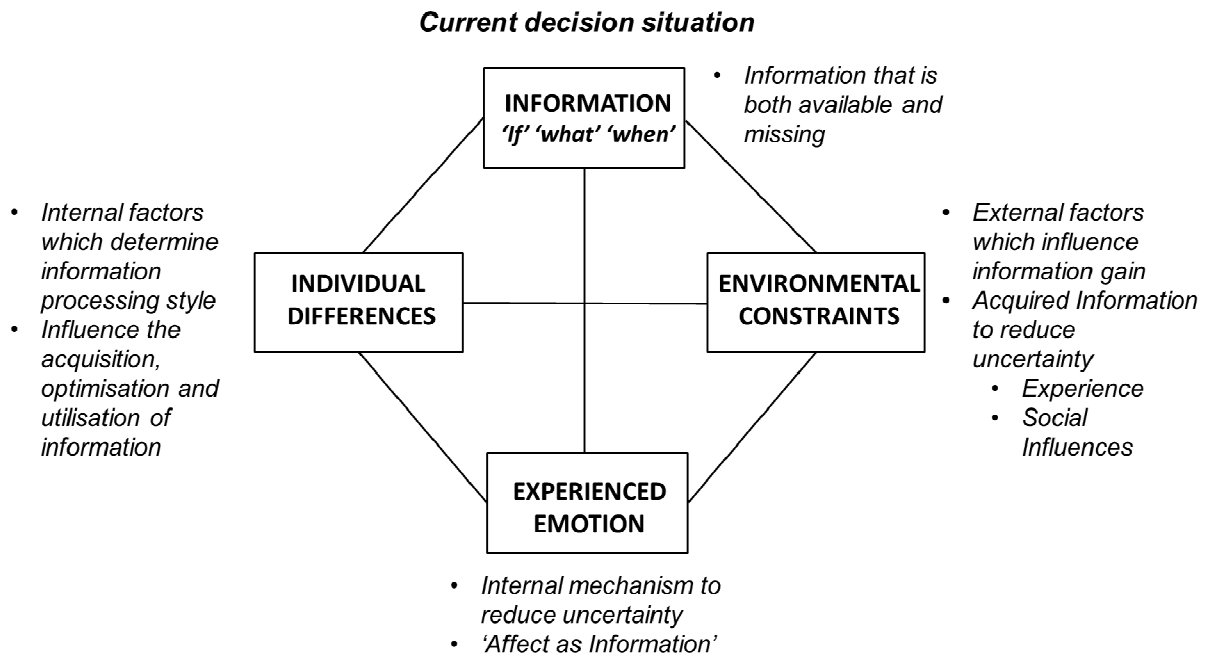


Figure 7.2. 'Information Availability' Framework for Decision Making under Uncertainty.

Decision making requires an interaction between the four components in order to reduce uncertainty, i.e. acquire additional information about 'if', 'what' and 'when'. Information may be acquired through either or both external and internal sources. Information can be acquired from the external environment through direct experience, e.g. learning, and/or through social interactions. Information can also be internally derived via emotional responses to missing information, e.g. 'affect as information'. Both individual differences and environmental constraints influence the degree to which additional information may be acquired, and also influence the emotions that are experienced.

In terms of applicability, this framework raises several possibilities that intervention strategies could target. For instance, considering the external environment as a source of intervention, delivering information about the future consequences of current behaviours could benefit from framing in a manner that makes delayed consequences appear more salient and tangible, e.g. through either affective connotations such as visual imagery of future desired state/self) or via descriptions that limit attention to time dimensions and emphasise near certainty (acknowledgeable, future outcomes can never be predicted with 100 % certainty, but displaying near certainty outcomes, such as 80%

could lessen impact of uncertainty). Alternatively, interventions could target the internal environment. For example, screening intervention participants on the basis of motivational and affective tendencies, and tailoring reward incentive schedules to match desired preferences could enhance efficacy and longevity of intervention strategies. Equally, interventions that based on mindfulness focus on enhancing attentional processes, and have been found effective for improving emotional and psychological well-being (e.g. Nyliček & Kuijpers, 2008; Van Son, Nyliček, Pop & Pouwer, 2011). Such techniques could be extended to provide internal affective Responses in situations information about *‘if’*, *‘what’* and or *‘when’* are missing.

7.6 Conclusion

The work presented in this thesis has demonstrated that decision making under uncertainty can be qualified beyond the dimension of probability, and that uncertainty may be characterised as a state of incomplete information about *‘if’* *what* and *‘when’* outcomes will occur. Intertemporal choice can be accommodated within this framework, and therefore be subject to the same cognitive and neural processes that underlie risky and ambiguous choices. People prefer certainty in terms of knowledge – confidence: certainty is cognitively more efficient and less demanding. Therefore choices are the result of a motivational process to reduce uncertainty, optimise the use of known information and/or seek to complete information gaps, factually or emotionally. Consequently, this framework allows for the design of behavioural interventions that specifically target reducing uncertainties of *‘if’*, *‘what’* or *‘when’*.

References

- Ainslie, G. (1975). Specious Reward - Behavioral Theory of Impulsiveness and Impulse Control. *Psychological Bulletin*, 82(4), 463-496.
- Alexander, D. M., Hermens, D. F., Keage, H. A. D., Clark, C. R., Williams, L. M., Kohn, M. R., et al. (2008). Event-related wave activity in the EEG provides new marker of ADHD. *Clinical Neurophysiology*, 119(1), 163-179.
- Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences*, 108(25), 10367-10371.
- Andrews, J. A., Tildesley, E., Hops, H., & Li, F. (2002). The influence of peers on young adult substance use. *Health psychology: official journal of the Division of Health Psychology, American Psychological Association*, 21(4), 349-357.
- Appelt, K. C., Milch, K. F., Handgraaf, M. J. J., & Weber, E. U. (2011). The decision making individual differences inventory and guidelines for the study of individual differences in judgment and decision-making research. *Judgment and Decision Making*, 6(3), 252-262.
- Ariely, D., & Loewenstein, G. (2000). When Does Duration Matter in Judgment and Decision Making? *Journal of Experimental Psychology: General* 129(4), 508-523.
- Ariely, D., & Norton, M. I. (2008). How actions create - not just reveal - preferences. *Trends in Cognitive Sciences*, 12(1), 13-16.
- Armel, C. K., Beaumel, A., & Rangel, A. (2008). Biasing simple choices by manipulating relative visual attention. *Judgment and Decision Making*, 3(5), 396-403.
- Åstebro, T., Jeffrey, S. A., & Adomdza, G. K. (2007). Inventor perseverance after being told to quit: the role of cognitive biases. *Journal of Behavioral Decision Making*, 20(3), 253-272.
- Augustine, A. A., & Larsen, R. J. (2011). Affect Regulation and Temporal Discounting: Interactions Between Primed, State, and Trait Affect. *Emotion April*, 11(2), 403-412.
- Bagneux, V., Bollon, T., & Dantzer, C (2011). Do (un)certainly appraisal tendencies reverse the influence of emotions on risk taking in sequential tasks? *Cognition & Emotion*, 26(3)568-576.
- Baker, F., Johnson, M. W., & Bickel, W. K. (2003). Delay Discounting in Current and Never-Before Cigarette Smokers: Similarities and Differences Across Commodity, Sign, and Magnitude. *Journal of Abnormal Psychology August*, 112(3), 382-392.
- Ballard, K., & Knutson, B. (2009). Dissociable neural representations of future reward magnitude and delay during temporal discounting. *NeuroImage*, 45(1), 143-150.
- Barkley, R. A., Edwards, G., Laneri, M., Fletcher, K., & Metevia, L. (2001). Executive Functioning, Temporal Discounting, and Sense of Time in Adolescents with

- Attention Deficit Hyperactivity Disorder (ADHD) and Oppositional Defiant Disorder (ODD). *Journal of Abnormal Child Psychology*, 29(6), 541-556.
- Barron, G., & Leider, S. (2010). The role of experience in the Gambler's Fallacy. *Journal of Behavioral Decision Making*, 23(1), 117-129.
- Baxter, M., & Murray, E. A. (2002). The amygdala and reward. *Nature Reviews Neuroscience*, 3(7), 563-573.
- Baxter, M. G., Parker, A., Lindner, C. C. C., Izquierdo, A. D., & Murray, E. A. (2000). Control of response selection by reinforcer value requires interaction of amygdala and orbitofrontal cortex. *Journal of Neuroscience*, 20, 4311-4319.
- Bechara, A. (2003). Risky Business: Emotion, Decision-Making, and Addiction. *Journal of Gambling Studies*, 19(1), 23-51.
- Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: a neurocognitive perspective. *Nature Neuroscience*, 8(11), 1458-1463.
- Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, 50, 7-15.
- Bechara, A., & Damasio, H. (2002). Decision-making and addiction (part I): impaired activation of somatic states in substance dependent individuals when pondering decisions with negative future consequences. *Neuropsychologia*, 40(10), 1675-1689.
- Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex*, 10, 295-307.
- Bechara, A., Damasio, H., Damasio, A. R., & Lee, G. P. (1999). Different Contributions of the Human Amygdala and Ventromedial Prefrontal Cortex to Decision-Making. *Journal of Neuroscience*, 19(13), 5473-5481.
- Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding Advantageously Before Knowing the Advantageous Strategy. *Science*, 275(5304), 1293-1295.
- Behrens, T. E. J., Woolrich, M. W., Walton, M. E., & Rushworth, M. F. S. (2007). Learning the value of information in an uncertain world. *Nature Neuroscience*, 10(9), 1214-1221.
- Bellebaum, C., Poleszki, D., & Daum, I. (2010). It is less than you expected: The feedback-related negativity reflects violations of reward magnitude expectations. *Neuropsychologia*, 48(11), 3343-3350.
- Bensi, L., & Guisberti, F. (2007). Trait anxiety and reasoning under uncertainty. *Personality & Individual Differences*, 43(4), 827-838.
- Berger, C. R., & Calabrese, R. J. (1975). Some Explorations in Initial Interaction and Beyond: toward a developmental theory of interpersonal communication. *Human Communication Research*, 1(2), 99-112.

- Berlin, H. A., Rolls, E. T., & Kischka, U. (2004). Impulsivity, time perception, emotion and reinforcement sensitivity in patients with orbitofrontal cortex lesions. *Brain*, 127(5), 1108-1126.
- Berns, G. S., Laibson, D., & Loewenstein, G. (2007). Intertemporal choice - toward an integrative framework. [doi: DOI: 10.1016/j.tics.2007.08.011]. *Trends in Cognitive Sciences*, 11(11), 482-488.
- Berridge, K. C. (2007). The debate over dopamine's role in reward: the case for incentive salience. *Psychopharmacology*, 191(3), 391-431.
- Berridge, K. C., & Robinson, T. E. (1998). What is the role of dopamine in reward: hedonic impact, reward learning, or incentive salience? *Brain Research Reviews*, 28(3), 309-369.
- Betsch, T., Haberstroh, S., Glöckner, A., Haar, T., & Fiedler, K. (2001). The Effects of Routine Strength on Adaptation and Information Search in Recurrent Decision Making. *Organizational Behavior and Human Decision Processes*, 84(1), 23-53.
- Bickel, W. K., Miller, M. L., Yi, R., Kowal, B. P., Lindquist, D. M., & Pitcock, J. A. (2007). Behavioral and neuroeconomics of drug addiction: Competing neural systems and temporal discounting processes. *Drug and Alcohol Dependence*, 90(Supplement 1), S85-S91.
- Bickel, W. K., Odum, A. L., & Madden, G. J. (1999). Impulsivity and cigarette smoking: delay discounting in current, never, and ex-smokers. *Psychopharmacology*, 146(4), 447-454.
- Bickel, W. K., Yi, R., Landes, R. D., Hill, P. F., & Baxter, C. (2011). Remember the Future: Working Memory Training Decreases Delay Discounting Among Stimulant Addicts. *Biological Psychiatry*, 69(3), 260-265.
- Bjork, J. M., Smith, A. R., & Hommer, D. W. (2008). Striatal sensitivity to reward deliveries and omissions in substance dependent patients. *NeuroImage*, 42(4), 1609-1621.
- Bobova, L., Finn, P. R., Rickert, M. E., & Lucas, J. (2009). Disinhibitory Psychopathology and Delay Discounting in Alcohol Dependence: Personality and Cognitive Correlates. *Experimental and Clinical Psychopharmacology*, 17(1), 51-61.
- Boettiger, C. A., Mitchell, J. M., Tavares, V. C., Robertson, M., Joslyn, G., D'Esposito, M., et al. (2007). Immediate Reward Bias in Humans: Fronto-Parietal Networks and a Role for the Catechol-O-Methyltransferase 158Val/Val Genotype. *Journal of Neuroscience*, 27(52), 14383-14391.
- Bonaccio, S., & Dalal, R. S. (2006). Advice taking and decision-making: An integrative literature review, and implications for the organizational sciences. *Organizational Behavior and Human Decision Processes*, 101(2), 127-151.
- Bonaccio, S., & Dalal, R. S. (2010). Evaluating advisors: A policy-capturing study under conditions of complete and missing information. *Journal of Behavioral Decision Making*, 23(3), 227-249.

- Borghans, L., Golsteyn, B. H. H., Heckman, J., & Humphries, J. E. (2011). Identification problems in personality psychology. *Personality and Individual Differences*, 51(3), 315-320.
- Brand, M., & Altstötter-Gleich, C. (2008). Personality and decision-making in laboratory gambling tasks - Evidence for a relationship between deciding advantageously under risk conditions and perfectionism. *Personality and Individual Differences*, 45(3), 226-231.
- Brand, M., Labudda, K., & Markowitsch, H. J. (2006). Neuropsychological correlates of decision-making in ambiguous and risky situations. *Neural Networks*, 19(8), 1266-1276.
- Brand, M., Recknor, E. C., Grabenhorst, F., & Bechara, A. (2007). Decisions under ambiguity and decisions under risk: Correlations with executive functions and comparisons of two different gambling tasks with implicit and explicit rules. *Journal of Clinical and Experimental Neuropsychology*, 29(1), 86 - 99.
- Breiter, H. C., Aharon, I., Kahneman, D., Dale, A., & Shizgal, P. (2001). Functional Imaging of Neural Responses to Expectancy and Experience of Monetary Gains and Losses. *Neuron*, 30(2), 619-639.
- Brown, C., El-Deredy, W., & Blanchette, I. (2010). Attentional modulation of visual-evoked potentials by threat: Investigating the effect of evolutionary relevance. *Brain and Cognition*, 74(3), 281-287.
- Brown, J., Broderick, A. J., & Lee, N. (2007). Word of mouth communication within online communities: Conceptualizing the online social network. *Journal of Interactive Marketing*, 21(3), 2-20.
- Budescu, D. V., & Rantilla, A. K. (2000). Confidence in aggregation of expert opinions. *Acta Psychologica*, 104(3), 371-398.
- Buelow, M., & Suhr, J. (2009). Construct Validity of the Iowa Gambling Task. *Neuropsychology Review*, 19(1), 102-114.
- Buhusi, C. V., & Meck, W. H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. *Nature Reviews Neuroscience*, 6(10), 755-765.
- Busemeyer, J. R., & Townsend, J. T. (1993). Decision Field Theory: A Dynamic-Cognitive Approach to Decision Making in an Uncertain Environment. *Psychological Review* July, 100(3), 432-459.
- Butzer, B., & Kuiper, N. A (2006). Relationships between the frequency of social comparisons and self-concept clarity, intolerance of uncertainty, anxiety and depression. *Personality & Individual Differences*, 41(1), 167-176.
- Caldwell, D. F., & Burger, J. M. (2009). Learning about unchosen alternatives: When does curiosity overcome regret avoidance? *Cognition & Emotion*, 23(8), 1630-1639.
- Camilleri, A. R., & Newell, B. R. (2011). Description- and experience-based choice: Does equivalent information equal equivalent choice? *Acta Psychologica*, 136(3), 276-284.

- Carpenter, J., Garcia, J., & Lum, J. (2011). Dopamine receptor genes predict risk preferences, time preferences, and related economic choices. *Journal of Risk and Uncertainty*, 42(3), 233-261.
- Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, 51(13), 1484-1525.
- Carretié, L., Hinojosa, J. A., Martín-Loeches, M., Mercado, F., & Tapia, M. (2004). Automatic attention to emotional stimuli: Neural correlates. *Human Brain Mapping*, 22(4), 290-299.
- Carter, R. M., Meyer, J. R., & Huettel, S. A. (2010). Functional Neuroimaging of Intertemporal Choice Models: A Review. *Journal of Neuroscience, Psychology, and Economics*, 3(1), 27-45.
- Carver, C. S., Sutton, S. K., & Scheier, M. F. (2000). Action, Emotion, and Personality: Emerging Conceptual Integration. *Personality and Social Psychology Bulletin*, 26(6), 741-751.
- Carver, C. S., & White, T. L. (1994). Behavioral Inhibition, Behavioral Activation, and Affective Responses to Impending Reward and Punishment: The BIS/BAS Scales. *Journal of Personality & Social Psychology*, 67(2), 319-333.
- Chapman, G. B. (1996). Temporal discounting and utility for health and money. *Learning, Memory, and Cognition*, 22(3), 771-791.
- Chapman, G. B., Brewer, N. T., Coups, E. J., Brownlee, S., Leventhal, H., & Leventhal, E. A. (2001). Value for the future and preventive health behavior. *Journal of Experimental Psychology: Applied*, 7(3), 235-250.
- Chapman, G. B., & Elstein, A. S. (1995). Valuing the Future: Temporal Discounting of Health and Money. *Medical Decision Making*, 15(4), 373-386.
- Chapman, G. B., & Liu, J. (2009). Numeracy, frequency, and bayesian reasoning. *Judgment and Decision Making*, 4(1), 34-40.
- Chapman, K. W., Grace-Martin, K., & Lawless, H. T. (2006). Expectations and the stability of preference choice. *Journal of Sensory Studies*, 21(4), 441-455.
- Charlton, S. R., & Fantino, E. (2008). Commodity specific rates of temporal discounting: Does metabolic function underlie differences in rates of discounting? *Behavioural Processes*, 77(3), 334-342.
- Chi, S. E., Park, C. B., Lim, S. L., Park, E. H., Lee, Y. H., Lee, K. H., et al. (2005). EEG and personality dimensions: A consideration based on the brain oscillatory systems. *Personality and Individual Differences*, 39(3), 669-681.
- Clore, G. L., Gasper, K., & Garvin, E. (2001). Affect as information. In J. P. Forgas (Ed), *Handbook of affect and social cognition* (pp. 121-144). Mahwah, NJ: Erlbaum.
- Clore, G. L., & Huntsinger, J. R. (2007). How emotions inform judgment and regulate thought. *Trends in Cognitive Sciences*, 11(9), 393-399.

- Codispoti, M., Ferrari, V., & Bradley, M. M. (2006). Repetitive picture processing: Autonomic and cortical correlates. *Brain Research*, 1068(1), 213-220.
- Coffey, S. F., Gudleski, G. D., Saladin, M. E., & Brady, K. T. (2003). Impulsivity and Rapid Discounting of Delayed Hypothetical Rewards in Cocaine-Dependent Individuals. *Experimental and Clinical Psychopharmacology*, 11(1), 18-25.
- Cohen, M. X., Wilmes, K., & van de Vijver, I. (2011). Cortical electrophysiological network dynamics of feedback learning. [doi: 10.1016/j.tics.2011.10.004]. *Trends in Cognitive Sciences*, 15(12), 558-566.
- Collins, E. C., Percy, E. J., Smith, E. R., & Kruschke, J. K. (2011). Integrating advice and experience: Learning and decision making with social and nonsocial cues. *Journal of Personality and Social Psychology*, 100(6), 967-982.
- Colombetti, G. (2008). The Somatic Marker Hypotheses, and What the Iowa Gambling Task Does and Does not Show. *The British Journal for the Philosophy of Science*, 59(1), 51-71.
- Congdon, E., & Canli, T. (2005). The Endophenotype of Impulsivity: Reaching Consilience Through Behavioral, Genetic, and Neuroimaging Approaches. *Behavioral and Cognitive Neuroscience Reviews*, 4(4), 262-281.
- Coppin, G. r., Delplanque, S., Cayeux, I., Porcherot, C., & Sander, D. (2010). I'm No Longer Torn After Choice. *Psychological Science*, 21(4), 489-493.
- Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nat Rev Neurosci*, 3(3), 201-215.
- Coricelli, G., & Rustichini, A. (2009). Reward-based emotions: affective evaluation of outcomes and regret learning. In D. Dr. Jean-Claude & T. Léon (Eds.), *Handbook of Reward and Decision Making* (pp. 427-439). New York: Academic Press.
- Costa, P. T., & McCrae, R. R. (1989). The NEO-PI/NEO-FFI manual supplement, Psychological Assessment Resources, Odessa, FL.
- Costa, P. T., & McCrae, R. R. (1992). Normal Personality Assessment in Clinical Practice: The NEO Personality Inventory. *Psychological Assessment*, 4(1), 5-13.
- Cowan, N. (2010). The magical mystery four. *Current Directions in Psychological Science*, 19(1), 51-57.
- Critchley, H. D., Mathias, C. J., & Dolan, R. J. (2001). Neural activity in the human brain relating to uncertainty and arousal during anticipation. *Neuron*, 29, 537-545.
- Critchley, H. D., & Rolls, E. T. (1996). Hunger and satiety modify the responses of olfactory and visual neurons in the primate orbitofrontal cortex. *Journal of Neurophysiology*, 75(4), 1673-1686.
- Curley, S. P., Yates, J. F., & Abrams, R. A. (1986). Psychological sources of ambiguity avoidance. *Organizational Behavior and Human Decision Processes*, 38(2), 230-256.

- D'Argembeau, A., & Van der Linden, M. (2006). Individual differences in the phenomenology of mental time travel: The effect of vivid visual imagery and emotion regulation strategies. *Consciousness and Cognition*, 15(2), 342-350.
- Dalal, R. S., & Bonaccio, S. (2010). What types of advice do decision-makers prefer? *Organizational Behavior and Human Decision Processes*, 112(1), 11-23.
- Damasio, A. R. (1994). *Descartes' Error: Emotion, Reason, and the Human Brain*. New York, NY: Penguin Books.
- Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences*, 351(1346), 1413-1420.
- Danner, U. N., Ouwehand, C., van Haastert, N. L., Hornsveld, H., & de Ridder, D. T. D. (2012). Decision-making Impairments in Women with Binge Eating Disorder in Comparison with Obese and Normal Weight Women. *European Eating Disorders Review*, 20(1), e56-e62.
- Dawe, S., Gullo, M. J., & Loxton, N. J. (2004). Reward drive and rash impulsiveness as dimensions of impulsivity: Implications for substance misuse. *Addictive Behaviors*, 29(7), 1389-1405.
- De Martino, B., Kumaran, D., Seymour, B., & Dolan, R. J. (2006). Frames, Biases, and Rational Decision-Making in the Human Brain. *Science*, 313(5787), 684-687.
- de Wit, H., Enggasser, J. L., & Richards, J. B. (2002). Acute administration of d-amphetamine decreases impulsivity in healthy volunteers. *Neuropsychopharmacology*, 27(5), 813-825.
- de Wit, H., Flory, J. D., Acheson, A., McCloskey, M., & Manuck, S. B. (2007). IQ and nonplanning impulsivity are independently associated with delay discounting in middle-aged adults. *Personality and Individual Differences*, 42(1), 111-121.
- Del Missier, F., Mäntylä, T., & Bruine de Bruin, W. (2010). Executive functions in decision making: An individual differences approach. *Thinking & Reasoning*, 16(2), 69-97.
- Del Missier, F., Mäntylä, T., & de Bruin, W. B. (2011). Decision-making Competence, Executive Functioning, and General Cognitive Abilities. *Journal of Behavioral Decision Making*, in press.
- Delgado, M. R., Locke, H. M., Stenger, V. A., & Fiez, J. A. (2003). Dorsal striatum responses to reward and punishment: Effects of valence and magnitude manipulations. *Cognitive, Affective and Behavioral Neuroscience*, 3(1), 27-38.
- Della Libera, C., & Chelazzi, L. (2006). Visual Selective Attention and the Effects of Monetary Rewards. *Psychological Science*, 17(3), 222-227.
- Della Libera, C., & Chelazzi, L. (2009). Learning to Attend and to Ignore Is a Matter of Gains and Losses. *Psychological Science*, 20(6), 778-784.
- Delplanque, S., Lavoie, M. E., Hot, P., Silvert, L., & Sequeira, H. (2004). Modulation of cognitive processing by emotional valence studied through event-related potentials in humans. *Neuroscience Letters*, 356(1), 1-4.

- Demaree, H. A., DeDonno, M. A., Burns, K. J., & Erik Everhart, D. (2008). You bet: How personality differences affect risk-taking preferences. *Personality and Individual Differences*, 44(7), 1484-1494.
- Depue, R. A., & Collins, P. F. (1999). Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences*, 22(03), 491-517.
- Dijksterhuis, A., & Nordgren, L. F. (2006). A Theory of Unconscious Thought. *Perspectives on Psychological Science*, 1(2), 95-109.
- Dimoska, A., & Johnstone, S. J. (2007). Neural mechanisms underlying trait impulsivity in non-clinical adults: Stop-signal performance and event-related potentials. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 31(2), 443-454.
- Dixon, M. R., Marley, J., & Jacobs, E. A. (2003). Delay discounting by pathological gamblers. *Journal of Applied Behaviour*, 36(4), 449-458.
- Dom, G., De Wilde, B., Hulstijn, W., & Sabbe, B. (2007). Dimensions of impulsive behaviour in abstinent alcoholics. *Personality and Individual Differences*, 42(3), 465-476.
- Donchin, E. (1981). Surprise!... Surprise? *Psychophysiology*, 18(5), 493-513.
- Du, W., Green, L., & Myerson, J. (2002). Cross-cultural comparisons of discounting delayed and probabilistic rewards *Psychological Record*, 52(4), 479.
- Dunn, B. D., Dalgleish, T., & Lawrence, A. D. (2006). The somatic marker hypothesis: A critical evaluation. *Neuroscience & Biobehavioral Reviews*, 30(2), 239-271.
- Ebert, J. E. J. (2001). The role of cognitive resources in the valuation of near and far future events. *Acta Psychologica*, 108(2), 155-171.
- Ebert, J. E. J., & Prelec, D. (2007). The Fragility of Time: Time-Insensitivity and Valuation of the Near and Far Future. *Management Science*, 53(9), 1423-1438.
- Egan, S. T., Kambouropoulos, N., & Staiger, P. K. (2010). Rash-impulsivity, reward-drive and motivations to use ecstasy. *Personality and Individual Differences*, 48(5), 670-675.
- Egan, V., Deary, I., & Austin, E. (2000). The NEO-FFI: emerging British norms and an item-level analysis suggests N, A and C are more reliable than O and E. *Personality and Individual Differences*, 29(5), 907-920.
- Eimer, M., & Holmes, A. (2007). Event-related brain potential correlates of emotional face processing. *Neuropsychologia*, 45(1), 15-31.
- Eimer, M., Holmes, A., & McGlone, F. P. (2003). The role of spatial attention in the processing of facial expression: An ERP study of rapid brain responses to six basic emotions. *Cognitive, Affective and Behavioral Neuroscience*, 3(2), 97-110.
- Einhorn, H. J., & Hogarth, R. M. (1986). Decision Making Under Ambiguity. *The Journal of Business*, 59(4), S225-S250.

- Elia, J., Ambrosini, P. J., & Rapoport, J. L. (1999). Treatment of Attention-Deficit-Hyperactivity Disorder. *New England Journal of Medicine*, 340(10), 780-788.
- Elliott, R., Newman, J. L., Longe, O. A., & Deakin, J. F. (2003). Differential response patterns in the striatum and orbitofrontal cortex to financial reward in humans: a parametric functional magnetic resonance imaging study. *Journal of Neuroscience*, 23, 303-307.
- Elliott, R., Newman, J. L., Longe, O. A., & Deakin, J. F. W. (2003). Differential response patterns in the striatum and orbitofrontal cortex to financial reward in humans: A parametric functional magnetic resonance imaging study. *Journal of Neuroscience*, 23(1), 303-307.
- Ellsberg, D. (1961). Risk, Ambiguity, and the Savage Axioms. *Quarterly Journal of Economics*, 75, 643-669.
- Engelmann, J. B., Damaraju, E., Padmala, S., & Pessoa, L. (2009). Combined effects of attention and motivation on visual task performance: transient and sustained motivational effects. *Frontiers in Human Neuroscience*, 3(4), 1-17.
- Epper, T., Fehr-Duda, H., & Bruhin, A. (2011). Viewing the future through a warped lens: Why uncertainty generates hyperbolic discounting. *Journal of Risk and Uncertainty*, 43(3), 169-203.
- Estle, S., Green, L., Myerson, J., & Holt, D. (2006). Differential effects of amount on temporal and probability discounting of gains and losses. *Memory & Cognition*, 34(4), 914-928.
- Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2007). Discounting of Monetary and Directly Consumable Rewards. *Psychological Science*, 18(1), 58-63.
- Evenden, J. L. (1999). Varieties of impulsivity. *Psychopharmacology*, 146(4), 348-361.
- Evenden, J. L., & Ryan, C. N. (1999). The pharmacology of impulsive behaviour in rats VI: the effects of ethanol and selective serotonergic drugs on response choice with varying delays of reinforcement. *Psychopharmacology*, 146(4), 413-421.
- Fein, G., & Chang, M. (2008). Smaller feedback ERN amplitudes during the BART are associated with a greater family history density of alcohol problems in treatment-naïve alcoholics. *Drug and Alcohol Dependence*, 92(1-3), 141-148.
- Fellows, L. K. (2004). The Cognitive Neuroscience of Human Decision Making: A Review and Conceptual Framework. *Behav Cogn Neurosci Rev*, 3(3), 159-172.
- Fellows, L. K., & Farah, M. J. (2005). Different Underlying Impairments in Decision-making Following Ventromedial and Dorsolateral Frontal Lobe Damage in Humans. *Cereb. Cortex*, 15(1), 58-63.
- Ferguson, E., Heckman, J. J., & Corr, P. (2011). Personality and economics: Overview and proposed framework. *Personality and Individual Differences*, 51(3), 201-209.
- Festinger, L. (1954). A Theory of Social Comparison Processes. *Human Relations*, 7(2), 117-140.

- Festinger, L. (1957). *A theory of cognitive dissonance*. Stanford, CA: Stanford University Press.
- Field, M., Santarcangelo, M., Sumnall, H., Goudie, A., & Cole, J. (2006). Delay discounting and the behavioural economics of cigarette purchases in smokers: the effects of nicotine deprivation. *Psychopharmacology*, 186(2), 255-263.
- Figner, B., Knoch, D., Johnson, E. J., Krosch, A. R., Lisanby, S. H., Fehr, E., et al. (2010). Lateral prefrontal cortex and self-control in intertemporal choice. *Nature Neuroscience*, 13(5), 538-539.
- Figner, B., & Weber, E. U. (2011). Who Takes Risks When and Why? *Current Directions in Psychological Science*, 20(4), 211-216.
- Finkelstein, E. A. P., Linnan, L. A. S., Tate, D. F. P., & Birken, B. E. M. S. (2007). A Pilot Study Testing the Effect of Different Levels of Financial Incentives on Weight Loss Among Overweight Employees. *Journal of Occupational & Environmental Medicine*, 49(9), 981-989.
- Finucane, M. L., Alhakami, A., Slovic, P., & Johnson, S. M. (2000). The affect heuristic in judgments of risks and benefits. *Journal of Behavioral Decision Making*, 13(1), 1-17.
- Fiorillo, C. D., Tobler, P. N., & Schultz, W. (2003). Discrete coding of reward probability and uncertainty by dopamine neurons. *Science*, 299, 1898-1902.
- Fischer, I., & Budescu, D. V. (2005). When do those who know more also know more about how much they know? The development of confidence and performance in categorical decision tasks. *Organizational Behavior and Human Decision Processes*, 98(1), 39-53.
- Foti, D., Hajcak, G., & Dien, J. (2009). Differentiating neural responses to emotional pictures: Evidence from temporal-spatial PCA. *Psychophysiology*, 46(3), 521-530.
- Fox, C. R., & Hadar, L. (2006). "Decisions from experience" = sampling error + prospect theory: Reconsidering Hertwig, Barron, Weber & Erev (2004) *Judgment and Decision Making*, 1, 159-161.
- Franken, I. H. A., & Muris, P. (2005). Individual differences in decision-making. *Personality and Individual Differences*, 39(5), 991-998.
- Franken, I. H. A., & Muris, P. (2006). BIS/BAS personality characteristics and college students' substance use. *Personality and Individual Differences*, 40(7), 1497-1503.
- Frederick, S., Loewenstein, G., & O'Donoghue, T. (2002). Time discounting and time preference: A critical review. *Journal of Economic Literature*, 40(2), 351-401.
- Frisch, D., & Baron, J. (1988). Ambiguity and rationality. *Journal of Behavioral Decision Making*, 1(3), 149-157.
- Frith, C. D., & Singer, T. (2008). The role of social cognition in decision making. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1511), 3875-3886.

- Gable, P. A., & Harmon-Jones, E. (2011). Attentional states influence early neural responses associated with motivational processes: Local vs. global attentional scope and N1 amplitude to appetitive stimuli. *Biological Psychology*, 87(2), 303-305.
- Galdi, S., Arcuri, L., & Gawronski, B. (2008). Automatic Mental Associations Predict Future Choices of Undecided Decision-Makers. *Science*, 321(5892), 1100-1102.
- Gamboz, N., Brandimonte, M. A., & De Vito, S. (2010). The role of past in the simulation of autobiographical future episodes. *Experimental Psychology*, 57(6), 419-428.
- Gansler, D. A., Jerram, M. W., Vannorsdall, T. D., & Schretlen, D. J. (2011). Does the Iowa Gambling Task Measure Executive Function? *Archives of Clinical Neuropsychology*.
- Gardner, M., & Steinberg, L. (2005). Peer Influence on Risk Taking, Risk Preference, and Risky Decision Making in Adolescence and Adulthood: An Experimental Study. *Developmental Psychology*, 41(4), 625-635.
- Gehring, W. J., & Willoughby, A. R. (2002). The Medial Frontal Cortex and the Rapid Processing of Monetary Gains and Losses. *Science*, 295(5563), 2279-2282.
- Germeijs, V., & Verschuere, K. (2011). Indecisiveness and Big Five personality factors: Relationship and specificity. *Personality and Individual Differences*, 50(7), 1023-1028.
- Gigerenzer, G., & Gaissmaier, W. (2011). Heuristic Decision Making. *Annual Review of Psychology*, 62(1), 451-482.
- Gil, M., & De Marco, R. J. (2009). Honeybees learn the sign and magnitude of reward variations. *Journal of Experimental Biology*, 212(17), 2830-2834.
- Gino, F., & Moore, D. A. (2007). Effects of task difficulty on use of advice. *Journal of Behavioral Decision Making*, 20(1), 21-35.
- Gino, F., Shang, J., & Croson, R. (2009). The impact of information from similar or different advisors on judgment. *Organizational Behavior and Human Decision Processes*, 108(2), 287-302.
- Giordano, L. A., Bickel, W. K., Loewenstein, G., Jacobs, E. A., Marsch, L., & Badger, G. J. (2002). Mild opioid deprivation increases the degree that opioid-dependent outpatients discount delayed heroin and money. *Psychopharmacology*, 163(2), 174-182.
- Glimcher, P. W., & Rustichini, A. R. (2004). Neuroeconomics: the consilience of brain and decision. *Science*, 306, 447-452.
- Godek, J., & Murray, K. B. (2008). Willingness to pay for advice: The role of rational and experiential processing. *Organizational Behavior and Human Decision Processes*, 106(1), 77-87.
- Gottlieb, D. A., Weiss, T., & Chapman, G. B. (2007). The Format in Which Uncertainty Information Is Presented Affects Decision Biases. *Psychological Science*, 18(3), 240-246.

- Goudriaan, A. E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2006). Psychophysiological determinants and concomitants of deficient decision making in pathological gamblers. *Drug and Alcohol Dependence*, 84(3), 231-239.
- Gray, J. A. (1990). Brain Systems that Mediate both Emotion and Cognition. *Cognition & Emotion*, 4(3), 269 - 288.
- Green, L., & Myerson, J. (1993). Alternative frameworks for the analysis of self control. *Behavior and Philosophy*, 21, 37-47.
- Green, L., & Myerson, J. (1996). Exponential versus Hyperbolic Discounting of Delayed Outcomes: Risk and Waiting Time. *American Zoologist*, 36(4), 496-505.
- Green, L., & Myerson, J. (2004). A discounting framework for choice with delayed and probabilistic rewards. *Psychological Bulletin*, 130(5), 769-792.
- Green, L., Myerson, J., & Fristoe, N. (1994). Temporal discounting and preference reversals in choice between delayed outcomes. *Psychonomic Bulletin & Review*, 1(3), 383-389.
- Green, L., Myerson, J., Lichtman, D., Rosen, S., & Fry, A. (1996). Temporal Discounting in Choice Between Delayed Rewards: The Role of Age and Income. *Psychology and Aging*, 11(1), 79-84.
- Green, L., Myerson, J., & McFadden, E. (1997). Rate of temporal discounting decreases with amount of reward. *Memory & Cognition*, 25(5), 715-723.
- Green, L., Myerson, J., & Ostaszewski, P. (1999). Amount of Reward Has Opposite Effects on the Discounting of Delayed and Probabilistic Outcomes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25(2), 418-427.
- Green, L., Myerson, J., Shah, A., K., Estle, S., J., & Holt, D., D. . (2007). Do Adjusting-Amount and Adjusting-Delay Procedures Produce Equivalent Estimates of Subjective Value in Pigeons? *Journal of the Experimental Analysis of Behaviour*, 87(3), 337-347.
- Gregorios-Pippas, L., Tobler, P. N., & Schultz, W. (2009). Short-Term Temporal Discounting of Reward Value in Human Ventral Striatum. *Journal of Neurophysiology*, 101(3), 1507-1523.
- Hajcak, G., Holroyd, C. B., Moser, J. S., & Simons, R. F. (2005). Brain potentials associated with expected and unexpected good and bad outcomes. *Psychophysiology*, 42(2), 161-170.
- Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. *Biological Psychology*, 71(2), 148-154.
- Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2007). It's worse than you thought: The feedback negativity and violations of reward prediction in gambling tasks. *Psychophysiology*, 44(6), 905-912.

- Hardisty, D. J., & Weber, E. U. (2009). Discounting Future Green: Money Versus the Environment. *Journal of Experimental Psychology: General*, 138(3), 329-340.
- Hare, T. A., Camerer, C. F., & Rangel, A. (2009). Self-Control in Decision-Making Involves Modulation of the vmPFC Valuation System. *Science*, 324(5927), 646-648.
- Hare, T. A., Malmaud, J., & Rangel, A. (2011). Focusing Attention on the Health Aspects of Foods Changes Value Signals in vmPFC and Improves Dietary Choice. *The Journal of Neuroscience*, 31(30), 11077-11087.
- Hariri, A. R., Brown, S. M., Williamson, D. E., Flory, J. D., de Wit, H., & Manuck, S. B. (2006). Preference for Immediate over Delayed Rewards Is Associated with Magnitude of Ventral Striatal Activity. *Journal of Neuroscience*, 26(51), 13213-13217.
- Harman, J. L. (2011). Individual differences in need for cognition and decision making in the Iowa Gambling Task. *Personality and Individual Differences*, 51(2), 112-116.
- Harries, C., Yaniv, I., & Harvey, N. (2004). Combining advice: the weight of a dissenting opinion in the consensus. *Journal of Behavioral Decision Making*, 17(5), 333-348.
- Harris, C. R. (2010). Feelings of dread and intertemporal choice. *Journal of Behavioral Decision Making*, 25(1), 13-28.
- Hart, W., Albarracin, D., Eagly, A. H., Brechan, I., Lindberg, M. J., & Merrill, L. (2009). Feeling Validated Versus Being Correct: A Meta-Analysis of Selective Exposure to Information. *Psychological Bulletin*, 135(4), 555-588.
- Harvey, N., & Fischer, I. (1997). Taking Advice: Accepting Help, Improving Judgment, and Sharing Responsibility. *Organizational Behavior and Human Decision Processes*, 70(2), 117-133.
- Hassani, O. K., Cromwell, H. C., & Schultz, W. (2001). Influence of Expectation of Different Rewards on Behavior-Related Neuronal Activity in the Striatum. *Journal of Neurophysiology*, 85(6), 2477-2489.
- Hau, R., Pleskac, T. J., Kiefer, J., & Hertwig, R. (2008). The description–experience gap in risky choice: the role of sample size and experienced probabilities. *Journal of Behavioral Decision Making*, 21(5), 493-518.
- Hausmann, D., & Läge, D. (2008). Sequential evidence accumulation in decision making: The individual desired level of confidence can explain the extent of information acquisition. *Judgment and Decision Making*, 3(3), 229-243.
- Heil, S. H., Johnson, M. W., Higgins, S. T., & Bickel, W. K. (2006). Delay discounting in currently using and currently abstinent cocaine-dependent outpatients and non-drug-using matched controls. *Addictive Behaviors*, 31(7), 1290-1294.

- Heilman, R. M., Crişan, L. G., Houser, D., Miclea, M., & Miu, A. C. (2010). Emotion Regulation and Decision Making Under Risk and Uncertainty. *Emotion*, 10(2), 257-265.
- Herman, C. P., & Polivy, J. (2003). Dieting as an exercise in behavioral economics. In: G. F. Loewenstein, D. Read, R. F. Baumeister (Eds), *Time and decision: economic and psychological perspectives on intertemporal choice* (pp. 459–489) .New York, NY: Russell Sage Foundation.
- Hertwig, R., Barron, G., Weber, E., U. , & Erev, I. (2004). Decisions From Experience and the Effect of Rare Events in Risky Choice. *Psychological Science*, 15(8), 534-539.
- Hertwig, R., Barron, G., Weber, E. U., & Erev, I. (2006). Rare risky prospects: Different when valued through a window of sampled experiences. In: K. Fiedler and P. Juslin (Eds.), *Information Sampling as a Key to Understanding Adaptive Cognition in an Uncertain Environment*. (pp. 72–91) New York, NY: Cambridge University Press. .
- Hertwig, R., & Erev, I. (2009). The description–experience gap in risky choice. *Trends in Cognitive Sciences*, 13(12), 517-523.
- Hertwig, R., & Gigerenzer, G. (2011). Behavioral Inconsistencies Do Not Imply Inconsistent Strategies. *Frontiers in Psychology*, 2:292.
- Hewig, J., Trippe, R. H., Hecht, H., Coles, M. G. H., Holroyd, C. B., & Miltner, W. H. R. (2008). An electrophysiological analysis of coaching in Blackjack. *Cortex*, 44(9), 1197-1205.
- Heym, N., Ferguson, E., & Lawrence, C. (2008). An evaluation of the relationship between Gray's revised RST and Eysenck's PEN: Distinguishing BIS and FFFS in Carver and White's BIS/BAS scales. *Personality and Individual Differences*, 45(8), 709-715.
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2010a). Reward Changes Salience in Human Vision via the Anterior Cingulate. *The Journal of Neuroscience*, 30(33), 11096-11103.
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2010b). Reward Guides Vision when It's Your Thing: Trait Reward-Seeking in Reward-Mediated Visual Priming. *PLoS ONE*, 5(11), e14087.
- Higgins, S. T., Alessi, S. M., & Dantona, R. L. (2002). Voucher-based incentives: A substance abuse treatment innovation. *Addictive Behaviors*, 27(6), 887-910.
- Hikosaka, K., & Watanabe, M. (2000). Delay activity of orbital and lateral prefrontal neurons of the monkey varying with different rewards. *Cerebral Cortex*, 10, 263-271.
- Hikosaka, K., & Watanabe, M. (2004). Long- and short-range reward expectancy in the primate orbitofrontal cortex. *European Journal of Neuroscience*, 19(4), 1046-1054.

- Hills, T. T., & Hertwig, R. (2010). Information Search in Decisions From Experience. *Psychological Science*, 21(12), 1787-1792.
- Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences of the United States of America*, 95(3), 781-787.
- Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 353(1373), 1257-1270.
- Hinson, J. M., Jameson, T. L., & Whitney, P. (2003). Impulsive Decision Making and Working Memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29(2), 298-306.
- Hirsh, J. B., Guindon, A., Morisano, D., & Peterson, J. B. (2010). Positive Mood Effects on Delay Discounting. *Emotion*, 10(5), 717-721.
- Hirsh, J. B., Morisano, D., & Peterson, J. B. (2008). Delay discounting: Interactions between personality and cognitive ability. *Journal of Research in Personality*, 42(6), 1646-1650.
- Hirsh, J. B., & Peterson, J. B. (2009). Extraversion, neuroticism, and the prisoner's dilemma. *Personality and Individual Differences*, 46(2), 254-256.
- Ho, M. Y., Mobini, S., Chiang, T. J., Bradshaw, C. M., & Szabadi, E. (1999). Theory and method in the quantitative analysis of impulsive choice behaviour: implications for psychopharmacology. *Psychopharmacology*, 146(4), 362-372.
- Hodgins, D. C., & Engel, A. B. (2002). Future Time Perspective in Pathological Gamblers. *Journal of Nervous & Mental Disease* 190(11), 775-780.
- Holroyd, C. B., & Coles, M. G. H. (2002). The Neural Basis of Human Error Processing: Reinforcement Learning, Dopamine, and the Error-Related Negativity. *Psychological Review*, 109(4), 679-709.
- Holroyd, C. B., & Coles, M. G. H. (2008). Dorsal anterior cingulate cortex integrates reinforcement history to guide voluntary behaviour. *Cortex*, 44(5), 548-559.
- Holroyd, C. B., Hajcak, G., & Larsen, J. T. (2006). The good, the bad and the neutral: Electrophysiological responses to feedback stimuli. *Brain Research*, 1105(1), 93-101.
- Holt, D., Green, L., Myerson, J., & Estle, S. (2008). Preference reversals with losses. *Psychonomic Bulletin & Review*, 15(1), 89-95.
- Housden, C. R., O'Sullivan, S. S., Joyce, E. M., Lees, A. J., & Roiser, J. P. (2010). Intact Reward Learning but Elevated Delay Discounting in Parkinson's Disease Patients With Impulsive-Compulsive Spectrum Behaviors. *Neuropsychopharmacology*, 35(11), 2155-2164.
- Hsu, M., Bhatt, M., Adolphs, R., Tranel, D., & Camerer, C. F. (2005). Neural Systems Responding to Degrees of Uncertainty in Human Decision-Making. *Science*, 310(5754), 1680-1683.

- Huettel, S. A. (2010). Ten Challenges for Decision Neuroscience. *Frontiers in Neuroscience*, 4: 171
- Idson, L. C., Liberman, N., & Higgins, E. T. (2004). Imagining How You'd Feel: The Role of Motivational Experiences from Regulatory Fit. *Personality and Social Psychology Bulletin*, 30(7), 926-937.
- Ivry, R. B., & Spencer, R. M. C. (2004). The neural representation of time. *Current Opinion in Neurobiology*, 14(2), 225-232.
- Izawa, E., Aoki, N., & Matsushima, T. (2005). Neural correlates of the proximity and quantity of anticipated food rewards in the ventral striatum of domestic chicks. *European Journal of Neuroscience*, 22(6), 1502-1512.
- Jackson, C., Geddes, R., Haw, S., & Frank, J. (2011). Interventions to prevent substance use and risky sexual behaviour in young people: a systematic review. *Addiction*, (in Press).
- Janis, I. B., & Nock, M. K. (2009). Are self-injurers impulsive?: Results from two behavioral laboratory studies. *Psychiatry Research*, 169(3), 261-267.
- Jeffery, R. W., Gerber, W. M., Rosenthal, B. S., & Lindquist, R. A. (1983). Monetary contracts in weight control: Effectiveness of group and individual contracts of varying size. *Journal of Consulting and Clinical Psychology*, 51(2), 242-248.
- Jessup, R. K., Bishara, A. J., & Busemeyer, J. R. (2008). Feedback Produces Divergence From Prospect Theory in Descriptive Choice. *Psychological Science*, 19(10), 1015-1022.
- Joireman, J., Anderson, J., & Strathman, A. (2003). The Aggression Paradox: Understanding Links Among Aggression, Sensation Seeking, and the Consideration of Future Consequences. *Journal of Personality & Social Psychology* June, 84(6), 1287-1302.
- Jones, S., & Oaksford, M. (2011). Transactional Problem Content in Cost Discounting: Parallel Effects for Probability and Delay. *Journal of Experimental Psychology: Learning, Memory, & Cognition* May, 37(3), 739-747.
- Kable, J. W., & Glimcher, P. W. (2010). An "As Soon As Possible" Effect in Human Intertemporal Decision Making: Behavioral Evidence and Neural Mechanisms. *Journal of Neurophysiology*, 103(5), 2513-2531.
- Kacelnik, A., & Bateson, M. (1996). Risky theories: the effects of variance on foraging decisions. *American Zoologist*, 36, 402-434.
- Kagel, J. H., Green, L., & Caraco, T. (1986). When foragers discount the future: constraint or adaptation? *Animal Behaviour*, 34(1), 271-283.
- Kahneman, D., & Snell, J. (1992). Predicting a changing taste: Do people know what they will like? *Journal of Behavioral Decision Making*, 5(3), 187-200.
- Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, 47(2), 263-291.

- Kahneman, D., & Tversky, A. (1982). Variants of uncertainty. *Cognition*, 11(2), 143-157.
- Kahneman, D., & Tversky, A. (1984). Choices, values and frames. *American Psychologist*, 39(4), 341-350.
- Kalenscher, T., Ohmann, T., & Gunturkun, O. (2006). The neuroscience of impulsive and self-controlled decisions. *International Journal of Psychophysiology*, 62(2), 203-211.
- Kalenscher, T., & Pennartz, C. M. A. (2008). Is a bird in the hand worth two in the future? The neuroeconomics of intertemporal decision-making. *Progress in Neurobiology*, 84(3), 284-315.
- Kamarajan, C., Rangaswamy, M., Tang, Y., Chorlian, D. B., Pandey, A. K., Roopesh, B. N., et al. (2010). Dysfunctional reward processing in male alcoholics: An ERP study during a gambling task. *Journal of Psychiatric Research*, 44(9), 576-590.
- Kane, R. L., Johnson, P. E., Town, R. J., & Butler, M. (2004). A structured review of the effect of economic incentives on consumers' preventive behavior. *American Journal of Preventive Medicine*, 27(4), 327-352.
- Kareev, Y., Arnon, S., & Horwitz-Zeliger, R. (2002). On the Misperception of Variability. *Journal of Experimental Psychology: General*, 131(2), 287-297.
- Keil, A., Bradley, M. M., Hauk, O., Rockstroh, B., Elbert, T., & Lang, P. J. (2002). Large-scale neural correlates of affective picture processing. *Psychophysiology*, 39(5), 641-649.
- Kellermann, K., & Reynolds, R. (1990). When Ignorance Is Bliss The Role of Motivation to Reduce Uncertainty in Uncertainty Reduction Theory. *Human Communication Research*, 17(1), 5-75.
- Keren, G., & Gerritsen, L. E. M. (1999). On the robustness and possible accounts of ambiguity aversion. *Acta Psychologica*, 103(1-2), 149-172.
- Keren, G., & Roelofsma, P. (1995). Immediacy and Certainty in Intertemporal Choice. *Organizational Behavior and Human Decision Processes*, 63(3), 287-297.
- Kim, B. K., & Zauberman, G. (2009). Perception of Anticipatory Time in Temporal Discounting. *Journal of Neuroscience, Psychology, and Economics*, 2(2), 91-101.
- Kim, D.-Y., & Lee, J.-H. (2011). Effects of the BAS and BIS on decision-making in a gambling task. *Personality and Individual Differences*, 50(7), 1131-1135.
- Kim, H., Shimojo, S., & O'Doherty, J. P. (2011). Overlapping Responses for the Expectation of Juice and Money Rewards in Human Ventromedial Prefrontal Cortex. *Cerebral Cortex*, 21(4), 769-776.
- Kirby, K. N., & Marakovic, N. N. (1996). Delay-discounting probabilistic rewards: rates decrease as amounts increase. *Psychonomic Bulletin & Review*, 3(1), 100-104.

- Kirby, K. N., Petry, N. M., & Bickel, W. K. (1999). Heroin Addicts Have Higher Discount Rates for Delayed Rewards Than Non-Drug-Using Controls. *Journal of Experimental Psychology: General*, 128(1), 78-87.
- Kirby, K. N., Winston, G. C., & Santiesteban, M. (2005). Impatience and grades: Delay-discount rates correlate negatively with college GPA. *Learning and Individual Differences*, 15(3), 213-222.
- Kirkebøen, G., & Teigen, K. H. (2011). Pre-outcome regret: Widespread and overlooked. *Journal of Behavioral Decision Making*, 24(3), 267-292.
- Kissler, J., Herbert, C., Winkler, I., & Junghofer, M. (2009). Emotion and attention in visual word processing--An ERP study. *Biological Psychology*, 80(1), 75-83.
- Knutson, B., Adams, C. M., Fong, G. W., & Hommer, D. (2001). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *Journal of Neuroscience*, 21(16), art. no.-RC159.
- Kobayashi, S., & Schultz, W. (2008). Influence of Reward Delays on Responses of Dopamine Neurons. *Journal of Neuroscience*, 28(31), 7837-7846.
- Kobbeltvedt, T., & Wolff, K. (2009). The Risk-as-feelings hypothesis in a Theory-of-planned-behaviour perspective. *Judgment and Decision Making*, 4(7), 567-586.
- Kriesler, K., & Nitzan, S. (2008). Is Context-Based Choice due to Context-Dependent Preferences? *Theory and Decision*, 64(1), 65-80.
- Krohne, H. W., & Hock, M. (2011). Anxiety, coping strategies and the processing of threatening information: Investigations with cognitive-experimental paradigms. *Personality & Individual Differences*, 50(7), 916-925.
- Kuhnen, C. M., & Knutson, B. (2005). The neural basis of financial risk taking. *Neuron*, 47, 763-770.
- Kusev, P., & Van Schaik, P. (2011). Preferences under risk: Content-dependent behaviour and psychological processing. *Frontiers in Psychology*, 2:269.
- Laibson, D. (1997). Golden eggs and hyperbolic discounting. *Quarterly Journal of Economics*, 112(2), 443-477.
- Landy, M. S., Goutcher, R., Trommershäuser, J., & Mamassian, P. (2007). Visual estimation under risk. *Journal of Vision*, 7(6), 1-15.
- Lane, S. D., Cherek, D. R., Pietras, C. J., & Tcheremissine, O. V. (2003). Measurement of delay discounting using trial-by-trial consequences. *Behavioural Processes*, 64(3), 287-303.
- Lange, S., Leue, A., & Beauducel, A. (2012). Behavioral approach and reward processing: Results on feedback-related negativity and P3 component. *Biological Psychology*, 89(2), 416-425.
- Lauriola, M., & Levin, I. P. (2001). Personality traits and risky decision-making in a controlled experimental task: an exploratory study. *Personality and Individual Differences*, 31(2), 215-226.

- Lebiere, C., & Anderson, J. R. (2011). Cognitive Constraints on Decision Making under Uncertainty. *Frontiers in Psychology*, 2:305.
- LeBoeuf, R. A. (2006). Discount Rates for Time Versus Dates: The Sensitivity of Discounting to Time-Interval Description. *Journal of Marketing Research*, 43(1), 59-59-72.
- Lee, D. (2005). Neuroeconomics: Making risky choices in the brain. *Nature Neuroscience*, 8(9), 1129-1130.
- Lee, M., & Cummins, T. (2004). Evidence accumulation in decision making: Unifying the “take the best” and the “rational” models. *Psychonomic Bulletin & Review*, 11(2), 343-352.
- Lejarraga, T. (2010). When experience is better than description: Time delays and complexity. *Journal of Behavioral Decision Making*, 23(1), 100-116.
- Lejarraga, T., & Gonzalez, C. (2011). Effects of feedback and complexity on repeated decisions from description. *Organizational Behavior and Human Decision Processes*, 116(2), 286-295.
- Leon, M. I., & Shadlen, M. N. (1999). Effect of Expected Reward Magnitude on the Response of Neurons in the Dorsolateral Prefrontal Cortex of the Macaque. *Neuron*, 24(2), 415-425.
- Leon, M. I., & Shadlen, M. N. (2003). Representation of time by neurons in the posterior parietal cortex of the Macaque. *Neuron*, 38(2), 317-327.
- Lerner, J. S., & Keltner, D. (2000). Beyond valence: Toward a model of emotion-specific influences on judgement and choice. *Cognition & Emotion*, 14(4), 473-493.
- Lewis, P. A., & Miall, R. C. (2003). Brain activation patterns during measurement of sub- and supra-second intervals. *Neuropsychologia*, 41(12), 1583-1592.
- Liberali, J. M., Reyna, V. F., Furlan, S., Stein, L. M., & Pardo, S. T. (2011). Individual Differences in Numeracy and Cognitive Reflection, with Implications for Biases and Fallacies in Probability Judgment. *Journal of Behavioral Decision Making*, n/a-n/a.
- Liberman, N., Sagristano, M. D., & Trope, Y. (2002). The effect of temporal distance on level of mental construal. *Journal of Experimental Social Psychology*, 38(6), 523-534.
- Lichtenstein, S., & Slovic, P. (2006). The construction of preference. New York: Cambridge University Press.
- Lin, C. H., Chiu, Y. C., Lee, P. L., & Hsieh, J. C. (2007). Is deck B a disadvantageous deck in the Iowa Gambling Task? *Behavioural and Brain Function*, 3, 16.
- Lipshitz, R., & Strauss, O. (1997). Coping with Uncertainty: A Naturalistic Decision-Making Analysis. *Organizational Behavior and Human Decision Processes*, 69(2), 149-163.

- Litt, A., Eliasmith, C., & Thagard, P. (2008). Neural affective decision theory: Choices, brains, and emotions. *Cognitive Systems Research*, 9(4), 252-273.
- Loewenstein, G. (1996). Out of Control: Visceral Influences on Behavior. *Organizational Behavior and Human Decision Processes*, 65(3), 272-292.
- Loewenstein, G., & Prelec, D. (1992). Anomalies in Intertemporal Choice: Evidence and an Interpretation. *The Quarterly Journal of Economics*, 107(2), 573-597.
- Loewenstein, G., Rick, S., & Cohen, J. D. (2008). Neuroeconomics. *Annual Review of Psychology*, 59(1), 647-672.
- Loewenstein, G., & Schkade, D. (1999). Wouldn't it be nice? Predicting future feelings. In Daniel Kahneman, Edward Diener, and Norbert Schwarz (Eds.). *Well-Being: The Foundations of Hedonic Psychology*, (pp. 85-105). New York: Russell Sage Foundation Press.
- Loewenstein, G. F., & Prelec, D. (1993). Preferences for Sequences of Outcomes. *Psychological Review January*, 100(1), 91-108.
- Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as Feelings. . *Psychological Bulletin*, 127(2), 267-286.
- Lönnqvist, J.-E., Verkasalo, M., & Walkowitz, G. (2011). It pays to pay – Big Five personality influences on co-operative behaviour in an incentivized and hypothetical prisoner's dilemma game. *Personality and Individual Differences*, 50(2), 300-304.
- Lopes, L. L. (1987). Between Hope and Fear: the psychology of risk. *Advances in Experiemtnal Social Psychology*, 29, 255-295.
- Luce, R. D. (2011). Inherent Individual Differences in Utility. [Opinion]. *Frontiers in Psychology*, 2.
- Luck, S. J. (2005). An introduction to the event-related potential technique. Cambridge, MA: MIT Press.
- Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences*, 4(11), 432-440.
- Luhmann, C. C. (2009). Temporal decision-making: insights from cognitive neuroscience. *Frontiers in Behavioral Neuroscience*, 3:39.
- Luhmann, C. C., Chun, M. M., Yi, D. J., Lee, D., & Wang, X. J. (2008). Neural dissociation of delay and uncertainty in intertemporal choice. *Journal of Neuroscience*, 28(53), 14459-14466.
- Luhmann, C. C., Ishida, K., & Hajcak, G. (2011). Intolerance of Uncertainty and Decisions About Delayed, Probabilistic Rewards. *Behavior Therapy*, 42(3), 378-386.
- Luijten, M., van Meel, C. S., & Franken, I. H. A. (2011). Diminished error processing in smokers during smoking cue exposure. *Pharmacology Biochemistry and Behavior*, 97(3), 514-520.

- Luo, S., Ainslie, G., Giragosian, L., & Monterosso, J. R. (2009). Behavioral and Neural Evidence of Incentive Bias for Immediate Rewards Relative to Preference-Matched Delayed Rewards. *The Journal of Neuroscience*, 29(47), 14820-14827.
- Luo, S., Ainslie, G., Pollini, D., Giragosian, L., & Monterosso, J. R. (2012). Moderators of the association between brain activation and farsighted choice. *NeuroImage*, 59(2), 1469-1477.
- Madden, G. J., Petry, N. M., Badger, G. J., & Bickel, W. K. (1997). Impulsive and self-control choices in opioid-dependent patients and non-drug-using control participants: Drug and monetary rewards. *Experimental and Clinical Psychopharmacology*, 5(3), 256-262.
- Malkoc, S. A., Zauberman, G., & Ulu, C. (2005). Consuming Now or Later? *Psychological Science*, 16(5), 411-417.
- Mangun, G. R., & Hillyard, S. A., 17, 1057-1074. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance*, 17, 1057-1074.
- Marco-Pallares, J., Cucurell, D., Cunillera, T., Kramer, U. M., Camara, E., Nager, W., et al. (2009). Genetic Variability in the Dopamine System (Dopamine Receptor D4, Catechol-O-Methyltransferase) Modulates Neurophysiological Responses to Gains and Losses. *Biological Psychiatry*, 66(2), 154-161.
- Mason, L., O'Sullivan, N., Blackburn, M., Bentall, R., & El-Deredy, W. (*in press*). I Want it Now! Neural Correlates of Hypersensitivity to Immediate Reward in Hypomania. *Biological Psychiatry*.
- Matsushima, T., Kawamori, A., & Bem-Sojka, T. (2008). Neuro-economics in chicks: Foraging choices based on amount, delay and cost. *Brain Research Bulletin*, 76(3), 245-252.
- Mazur, J. E. (1987). An Adjusting Procedure for Studying Delayed Reinforcement. In *M.L Commons, J.E. Mazur, J. A. Nevin & H. Rachlin (Eds). Quantitative analysis of behavior: V. The effect of delay and of intervening events on reinforcement value. (pp.55 -73)*. Hillsdale, N.J: Lawrence Erlbaum.
- McClure, S. M., Daw, N. D., & Read Montague, P. (2003). A computational substrate for incentive salience. *Trends in Neurosciences*, 26(8), 423-428.
- McClure, S. M., Ericson, K. M., Laibson, D. I., Loewenstein, G., & Cohen, J. D. (2007). Time discounting for primary rewards. *Journal of Neuroscience*, 27(21), 5796-5804.
- McClure, S. M., Laibson, D. I., Loewenstein, G., & Cohen, J. D. (2004). Separate Neural Systems Value Immediate and Delayed Monetary Rewards. *Science*, 306(5695), 503-507.
- McClure, S. M., Li, J., Tomlin, D., Cypert, K. S., Montague, L. M., & Montague, P. R. (2004). Neural Correlates of Behavioral Preference for Culturally Familiar Drinks. *Neuron*, 44(2), 379-387.

- Meck, W. H. (1996). Neuropharmacology of timing and time perception. *Cognitive Brain Research*, 3(3-4), 227-242.
- Meijers, M. H. C., & Stapel, D. A. (2011). Me tomorrow, the others later: How perspective fit increases sustainable behavior. *Journal of Environmental Psychology*, 31(1), 14-20.
- Mellers, B. A., & Schwartz, A. (1997). Decision Affect Theory: Emotional Reactions to the Outcomes of Risky Options. *Psychological Science*, 8(6), 423-429.
- Metcalf, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of willpower. *Psychological Review*, 106(1), 3-19.
- Mikels, J. A., Maglio, S. J., Reed, A. E., & Kaplowitz, L. J. (2011). Should I Go With My Gut? Investigating the Benefits of Emotion-Focused Decision Making. *Emotion*, 11(4), 743-753.
- Miller, E., Joseph, S., & Tudway, J. (2004). Assessing the component structure of four self-report measures of impulsivity. *Personality and Individual Differences*, 37(2), 349-358.
- Miller, G. A (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information, *Psychological Review*, 63(2), 81-97.
- Mir, P., Trender-Gerhard, I., Edwards, M., Schneider, S., Bhatia, K., & Jahanshahi, M. (2011). Motivation and movement: the effect of monetary incentive on performance speed. *Experimental Brain Research*, 209(4), 551-559.
- Mishra, S., & Lalumière, M. L. (2011). Individual differences in risk-propensity: Associations between personality and behavioral measures of risk. *Personality and Individual Differences*, 50(6), 869-873.
- Mitchell, S. H. (1999). Measures of impulsivity in cigarette smokers and non-smokers. *Psychopharmacology*, 146(4), 455-464.
- Mitchell, S. H. (2004). Effects of short-term nicotine deprivation on decision-making: Delay, uncertainty and effort discounting. *Nicotine and Tobacco Research*, 6(5), 819-828.
- Mitchell, S. H., & Wilson, V. B. (2010). The subjective value of delayed and probabilistic outcomes: Outcome size matters for gains but not for losses. *Behavioural Processes*, 83(1), 36-40.
- Mobini, S., Chiang, T. J., Al-Ruwaitea, A. S. A., Ho, M. Y., Bradshaw, C. M., & Szabadi, E. (2000). Effect of central 5-hydroxytryptamine depletion on inter-temporal choice: A quantitative analysis. *Psychopharmacology*, 149(3), 313-318.
- Mobini, S., Grant, A., Kass, A. E., & Yeomans, M. R. (2007). Relationships between functional and dysfunctional impulsivity, delay discounting and cognitive distortions. *Personality and Individual Differences*, 43(6), 1517-1528.
- Moller, A. C., Elliot, A. J., & Maier, M. A. (2009). Basic Hue-Meaning Associations. *Emotion*, 9(6), 898-902.

- Montague, P. R., & Berns, G. S. (2002). Neural Economics and the Biological Substrates of Valuation. *Neuron*, 36(2), 265-284.
- Montague, P. R., & King-Casas, B. (2007). Efficient statistics, common currencies and the problem of reward-harvesting. *Trends in Cognitive Sciences*, 11(12), 514-519.
- Montague, P. R., King-Casas, B., & Cohen, J. D. (2006). Imaging Valuation Models in Human Choice *Annual Review of Neuroscience*, 29(1), 417-448.
- Monterosso, J. R., & Luo, S. (2010). An Argument Against Dual Valuation System Competition: Cognitive Capacities Supporting Future Orientation Mediate Rather Than Compete With Visceral Motivations. *Journal of Neuroscience, Psychology, & Economics May*, 3(1), 1-14.
- Moser, J. S., & Simons, R. F. (2009). The neural consequences of flip-flopping: The feedback-related negativity and salience of reward prediction. *Psychophysiology*, 46(2), 313-320.
- Munro, G. E. S., Dywan, J., Harris, G. T., McKee, S., Unsal, A., & Segalowitz, S. J. (2007). Response inhibition in psychopathy: The frontal N2 and P3. *Neuroscience Letters*, 418(2), 149-153.
- Murphy, J. G., Vuchinich, R. E., & Simpson, C. A. (2001). Delayed Rewards and Cost Discounting *Psychological Record*, 51(4), 571.
- Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual choice. *Journal of Experimental Analysis Behaviour*, 64(3), 263-276.
- Myerson, J., Green, L., Scott Hanson, J., Holt, D. D., & Estle, S. J. (2003). Discounting delayed and probabilistic rewards: Processes and traits. *Journal of Economic Psychology*, 24(5), 619-635.
- Myerson, J., Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior*, 76(2), 235-243.
- Naqvi, N., Shiv, B., & Bechara, A. (2006). The role of emotion in decision making. A cognitive neuroscience perspective. *Current Directions in Psychological Science*, 15(5), 260 - 264.
- Nieuwenhuis, S., Yeung, N., Holroyd, C. B., Schurger, A., & Cohen, J. D. (2004). Sensitivity of electrophysiological activity from medial frontal cortex to utilitarian and performance feedback. *Cereb. Cort.*, 14, 741-747.
- Nummenmaa, L., Hietanen, J. K., Calvo, M. G., & Hyönä, J. (2011). Food Catches the Eye but Not for Everyone: A BMI-Contingent Attentional Bias in Rapid Detection of Nutriment. *PLoS ONE*, 6(5), e19215.
- Nykliček, I., & Kuijpers, K. (2008). Effects of mindfulness-based stress reduction intervention on psychological well-being and quality of life: is increased mindfulness indeed the mechanism? *Annals of Behavioural Medicine*, 35(3), 331-340.

- O'Connor, R. M., Stewart, S. H., & Watt, M. C. (2009). Distinguishing BAS risk for university students' drinking, smoking, and gambling behaviors. *Personality and Individual Differences*, 46(4), 514-519.
- Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*, 9(5), 242-249.
- Ochsner, K. N., Ray, R. R., Hughes, B., McRae, K., Cooper, J. C., Weber, J., et al. (2009). Bottom-Up and Top-Down Processes in Emotion Generation. *Psychological Science*, 20(11), 1322-1331.
- Odum, A. L. (2011). Delay discounting: Trait variable? *Behavioural Processes*, 87(1), 1-9.
- Odum, A. L., & Baumann, A. A. L. (2007). Cigarette smokers show steeper discounting of both food and cigarettes than money. *Drug and Alcohol Dependence*, 91(2-3), 293-296.
- Odum, A. L., Baumann, A. A. L., & Rimington, D. D. (2006). Discounting of delayed hypothetical money and food: Effects of amount. *Behavioural Processes*, 73(3), 278-284.
- Odum, A. L., Madden, G. J., Badger, G. J., & Bickel, W. K. (2000). Needle sharing in opioid-dependent outpatients: psychological processes underlying risk. *Drug and Alcohol Dependence*, 60(3), 259-266.
- Odum, A. L., & Rainaud, C. P. (2003). Discounting of delayed hypothetical money, alcohol, and food. *Behavioural Processes*, 64(3), 305-313.
- Ohmura, Y., Takahashi, T., & Kitamura, N. (2005). Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. *Psychopharmacology*, 182(4), 508-515.
- Ohmura, Y., Takahashi, T., Kitamura, N., & Wehr, P. (2006). Three-Month Stability of Delay and Probability Discounting Measures. *Experimental & Clinical Psychopharmacology*, 14(3), 318-328.
- Olson, E. A., Hooper, C. J., Collins, P., & Luciana, M. (2007). Adolescents' performance on delay and probability discounting tasks: Contributions of age, intelligence, executive functioning, and self-reported externalizing behavior. *Personality and Individual Differences*, 43(7), 1886-1897.
- Öncüler, A., & Onay, S. (2009). How do we evaluate future gambles? Experimental evidence on path dependency in risky intertemporal choice. *Journal of Behavioral Decision Making*, 22(3), 280-300.
- Ostaszewski, P., & Bialaszek, W. (2010). Probabilistic discounting in "certain gain-uncertain loss" and "certain loss-uncertain gain" conditions. *Behavioural Processes*, 83(3), 344-348.
- Paloyelis, Y., Asherson, P., Mehta, M. A., Faraone, S. V., & Kuntsi, J. (2010). DAT1 and COMT effects on delay discounting and trait impulsivity in male adolescents with attention deficit/hyperactivity disorder and healthy controls. *Neuropsychopharmacology*, 35(12), 2414-2426.

- Patak, M., & Reynolds, B. (2007). Question-based assessments of delay discounting: Do respondents spontaneously incorporate uncertainty into their valuations for delayed rewards? *Addictive Behaviors*, 32(2), 351-357.
- Paul-Ebhohimhen, V., & Avenell, A. (2008). Systematic review of the use of financial incentives in treatments for obesity and overweight. *Obesity Reviews*, 9(4), 355-367.
- Peirce, J. M., Petry, N. M., Stitzer, M. L., Blaine, J., Kellogg, S., Satterfield, F., et al. (2006). Effects of Lower-Cost Incentives on Stimulant Abstinence in Methadone Maintenance Treatment: A National Drug Abuse Treatment Clinical Trials Network Study. *Arch Gen Psychiatry*, 63(2), 201-208.
- Perales, J. C., Verdejo-Garcia, A., Moya, M., Lozano, O., & Perez-Garcia, M. (2009). Bright and dark sides of impulsivity: Performance of women with high and low trait impulsivity on neuropsychological tasks. *Journal of Clinical and Experimental Neuropsychology*, 31(8), 927-944.
- Pessoa, L. (2008). On the relationship between emotion and cognition. *Nat Rev Neurosci*, 9(2), 148-158.
- Pessoa, L., & Engelmann, J. B. (2010). Embedding reward signals into perception and cognition. *Frontiers in Neuroscience*, 4:17.
- Peters, J., & Büchel, C. (2009). Overlapping and distinct neural systems code for subjective value during intertemporal and risky decision making. *Journal of Neuroscience*, 29(50), 15727-15734.
- Peters, J., & Büchel, C. (2010). Episodic Future Thinking Reduces Reward Delay Discounting through an Enhancement of Prefrontal-Mediotemporal Interactions. *Neuron*, 66(1), 138-148.
- Peters, J., & Büchel, C. (2011). The neural mechanisms of inter-temporal decision-making: understanding variability. *Trends in Cognitive Sciences*, 15(5), 227-239.
- Petry, N. M. (2001). Delay discounting of money and alcohol in actively using alcoholics, currently abstinent alcoholics, and controls. *Psychopharmacology*, 154(3), 243-250.
- Petry, N. M. (2005). *Pathological gambling: Etiology, comorbidity, and treatment*. Washington, DC: American Psychological Association.
- Petry, N. M., Alessi, S. M., & Hanson, T. (2007). Contingency Management Improves Abstinence and Quality of Life in Cocaine Abusers. *Journal of Consulting & Clinical Psychology*, 75(2), 307-315.
- Petry, N. M., Bickel, W. K., & Arnett, M. (1998). Shortened time horizons and insensitivity to future consequences in heroin addicts. *Addiction*, 93(5), 729-738.
- Pfabigan, D. M., Alexopoulos, J., Bauer, H., & Sailer, U. (2010). Manipulation of feedback expectancy and valence induces negative and positive reward prediction error signals manifest in event-related brain potentials. *Psychophysiology*, 48(5), 656-664.

- Pham, M. T. (2007). Emotion and Rationality: A Critical Review and Interpretation of Empirical Evidence. *Review of General Psychology*, 11(2), 155-178.
- Pickens, C. L., Setlow, B., Saddoris, M. P., Gallagher, M., Holland, P., & Schoenbaum, G. (2003). Different roles for orbitofrontal cortex and basolateral amygdala in a reinforcer devaluation task. *Journal of Neuroscience*, 23, 11078-11084.
- Piech, R. M., Pastorino, M. T., & Zald, D. H. (2010). All I saw was the cake. Hunger effects on attentional capture by visual food cues. *Appetite*, 54(3), 579-582.
- Pine, A., Shiner, T., Seymour, B., & Dolan, R. J. (2010). Dopamine, Time, and Impulsivity in Humans. *Journal of Neuroscience*, 30(26), 8888-8896.
- Plassmann, H., O'Doherty, J., Shiv, B., & Rangel, A. (2008). Marketing actions can modulate neural representations of experienced pleasantness. *Proceedings of the National Academy of Sciences*, 105(3), 1050-1054.
- Pothos, E. M., Perry, G., Corr, P. J., Matthew, M. R., & Busemeyer, J. R. (2011). Understanding cooperation in the Prisoner's Dilemma game. *Personality and Individual Differences*, 51(3), 210-215.
- Potts, G. F. (2011). Impact of reward and punishment motivation on behavior monitoring as indexed by the error-related negativity. *International Journal of Psychophysiology*, 81(3), 324-331.
- Potts, G. F., Patel, S. H., & Azzam, P. N. (2004). Impact of instructed relevance on the visual ERP. *International Journal of Psychophysiology*, 52(2), 197-209.
- Prelec, D., & Loewenstein, G. (1991). Decision making over time and under uncertainty: A common approach *Management Science*, 37(7), 770-786.
- Price, P. C., & Stone, E. R. (2004). Intuitive evaluation of likelihood judgment producers: evidence for a confidence heuristic. *Journal of Behavioral Decision Making*, 17(1), 39-57.
- Quartz, S. R. (2009). Reason, emotion and decision-making: risk and reward computation with feeling. *Trends in Cognitive Sciences*, 13(5), 209-215.
- Quilty, L. C., & Oakman, J. M. (2004). The assessment of behavioural activation--the relationship between impulsivity and behavioural activation. *Personality and Individual Differences*, 37(2), 429-442.
- Rachlin, H., & Green, L. (1972). Commitment, Choice and Self Control. *Experimental Analysis of Behaviour*, 17(1), 15-22.
- Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective probability and delay. . *Journal of the Experimental Analysis of Behavior*, 55(2), 233-244.
- Rachlin, H., (2006). Notes on Discounting, *Journal of Experimental Analysis of Behaviour*, 85(3), 425-435.
- Raineri, A., & Rachlin, H. (1993). The effect of temporal constraints on the value of money and other commodities. *Journal of Behavioral Decision Making*, 6(2), 77-94.

- Rakow, T., Demes, K. A., & Newell, B. R. (2008). Biased samples not mode of presentation: Re-examining the apparent underweighting of rare events in experience-based choice. *Organizational Behavior and Human Decision Processes*, 106(2), 168-179.
- Rakow, T., Newell, B. R., & Zougkou, K. (2009). The role of working memory in information acquisition and decision making: lessons from the binary prediction task. *The Quarterly Journal of Experimental Psychology*, 63(7), 1335-1360.
- Rakow, T., & Newell, B. R. (2010). Degrees of uncertainty: An overview and framework for future research on experience-based choice. *Journal of Behavioral Decision Making*, 23(1), 1-14.
- Raymond, J. (2009). Interactions of attention, emotion and motivation. *Progress in Brain Research*, 176, 293-308.
- Read, D. (2001). Is Time-Discounting Hyperbolic or Subadditive? *Journal of Risk and Uncertainty*, 23(1), 5-32.
- Read, D., Frederick, S., Orsel, B., & Rahman, J. (2005). Four score and seven years from now: The date/delay effect in temporal discounting. *Management Science*, 51(9), 1326-1335.
- Read, D., & Roelofsma, P. H. M. P. (2003). Subadditive versus hyperbolic discounting: A comparison of choice and matching. *Organizational Behavior and Human Decision Processes*, 91(2), 140-153.
- Reyna, V. F., & Brainerd, C. J. (2008). Numeracy, ratio bias, and denominator neglect in judgments of risk and probability. *Learning and Individual Differences*, 18(1), 89-107.
- Reynolds, B. (2006). A review of delay-discounting research with humans: relations to drug use and gambling. *Behavioural Pharmacology* 17(8), 651-667.
- Reynolds, B., Ortengren, A., Richards, J. B., & de Wit, H. (2006). Dimensions of impulsive behavior: Personality and behavioral measures. *Personality and Individual Differences*, 40(2), 305-315.
- Reynolds, B., Patak, M., & Shroff, P. (2007). Adolescent smokers rate delayed rewards as less certain than adolescent nonsmokers. *Drug and Alcohol Dependence*, 90(2-3), 301-303.
- Reynolds, B., Richards, J. B., & de Wit, H. (2006). Acute-alcohol effects on the Experiential Discounting Task (EDT) and a question-based measure of delay discounting. *Pharmacology Biochemistry and Behavior*, 83(2), 194-202.
- Reynolds, B., Richards, J. B., Horn, K., & Karraker, K. (2004). Delay discounting and probability discounting as related to cigarette smoking status in adults. *Behavioural Processes*, 65(1), 35-42.
- Reynolds, B., & Schiffbauer, R. (2004). Measuring state changes in human delay discounting: an experiential discounting task. *Behavioural Processes*, 67(3), 343-356.

- Richards, J. B., Zhang, L., Mitchell, S. H., & de Wit, H. (1999). Delay or probability discounting in a model of impulsive behavior: Effect of alcohol. *Journal of the Experimental Analysis of Behavior*, 71(2), 121-143.
- Rick, S., & Loewenstein, G. (2008). Intangibility in intertemporal choice. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1511), 3813-3824.
- Robles, E., & Vargas, P. A. (2007). Functional parameters of delay discounting assessment tasks: Order of presentation. *Behavioural Processes*, 75(2), 237-241.
- Robles, E., & Vargas, P. A. (2008). Parameters of delay discounting assessment: Number of trials, effort, and sequential effects. *Behavioural Processes*, 78(2), 285-290.
- Roesch, M. R., Calu, D. J., & Schoenbaum, G. (2007). Dopamine neurons encode the better option in rats deciding between differently delayed or sized rewards. *Nature Neuroscience*, 10(12), 1615-1624.
- Roesch, M. R., & Olson, C. R. (2004). Neuronal Activity Related to Reward Value and Motivation in Primate Frontal Cortex. *Science*, 304(5668), 307-310.
- Roesch, M. R., & Olson, C. R. (2005). Neuronal Activity Dependent on Anticipated and Elapsed Delay in Macaque Prefrontal Cortex, Frontal and Supplementary Eye Fields, and Premotor Cortex. *Journal of Neurophysiology*, 94(2), 1469-1497.
- Roesch, M. R., Taylor, A. R., & Schoenbaum, G. (2006). Encoding of Time-Discounted Rewards in Orbitofrontal Cortex Is Independent of Value Representation. *Neuron*, 51(4), 509-520.
- Roitman, M. F., Stuber, G. D., Phillips, P. E. M., Wightman, R. M., & Carelli, R. M. (2004). Dopamine Operates as a Subsecond Modulator of Food Seeking. *Journal of Neuroscience*, 24(6), 1265-1271.
- Rolls, E. T. (1999). *The Brain and Emotion*. Oxford, UK: Oxford University Press.
- Rolls, E. T., & Grabenhorst, F. (2008). The orbitofrontal cortex and beyond: From affect to decision-making. *Progress in Neurobiology*, 86(3), 216-244.
- Roy, M. M., Christenfeld, N. J., & McKenzie, C. R. (2005). Underestimating the Duration of Future Events: Memory Incorrectly Used or Memory Bias? *Psychological Bulletin*, 131(5), 738-756.
- Samuelson, P. A. (1937). A Note on Measurement of Utility. *The Review of Economic Studies*, 4(2), 155-161.
- San Martín, R., Manes, F., Hurtado, E., Isla, P., & Ibañez, A. (2010). Size and probability of rewards modulate the feedback error-related negativity associated with wins but not losses in a monetarily rewarded gambling task. *NeuroImage*, 51(3), 1194-1204.
- Sanfey, A. G. (2007). Decision neuroscience: New directions in studies of judgment and decision making. *Current Directions in Psychological Science*, 16(3), 151-155.

- Sanfey, A. G. (2007). Social Decision-Making: Insights from Game Theory and Neuroscience. *Science*, 318(5850), 598-602.
- Sanfey, A. G., Loewenstein, G., McClure, S. M., & Cohen, J. D. (2006). Neuroeconomics: cross-currents in research on decision-making. *Trends in Cognitive Sciences*, 10(3), 108-116.
- Santesso, D. L., Bogdan, R., Birk, J. L., Goetz, E. L., Holmes, A. J., & Pizzagalli, D. A. (2011). Neural responses to negative feedback are related to negative emotionality in healthy adults. *Social Cognitive and Affective Neuroscience*.
- Santesso, D. L., Evins, A. E., Frank, M. J., Schetter, E. C., Bogdan, R., & Pizzagalli, D. A. (2009). Single dose of a dopamine agonist impairs reinforcement learning in humans: Evidence from event-related potentials and computational modeling of striatal-cortical function. *Human Brain Mapping*, 30(7), 1963-1976.
- Sato, W. C. A., Kochiyama, T., Yoshikawa, S., & Matsumura, M. (2001). Emotional expression boosts early visual processing of the face: ERP recording and its decomposition by independent component analysis. *NeuroReport*, 12(4), 709-714.
- Savage, L. J. (1954). *The Foundations of Statistics*. New York: John Wiley.
- Schacht, A., & Sommer, W. (2009). Emotions in word and face processing: Early and late cortical responses. *Brain and Cognition*, 69(3), 538-550.
- Schacter, D. L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: the prospective brain. *Nature Reviews Neuroscience*, 8(9), 657-661.
- Scheres, A., & Sanfey, A. (2006). Individual differences in decision making: Drive and reward responsiveness affect strategic bargaining in economic games. *Behavioral and Brain Functions*, 2(1), 35.
- Schmeltzer, C., Caverni, J.-P., & Warglien, M. (2004). How does preference reversal appear and disappear? Effects of the evaluation mode. *Journal of Behavioral Decision Making*, 17(5), 395-408.
- Schoenbaum, G., Chiba, A. A., & Gallagher, M. (1998). Orbitofrontal cortex and basolateral amygdala encode expected outcomes during learning. *Nature Neuroscience*, 1, 155-159.
- Schonberg, T., Fox, C. R., & Poldrack, R. A. (2011). Mind the gap: bridging economic and naturalistic risk-taking with cognitive neuroscience. *Trends in Cognitive Sciences*, 15(1), 11-19.
- Schotter, A. (2003). Decision making with naive advice. *American Economic Review*, 93(2), 196-201.
- Schultz, W. (1997). Dopamine neurons and their role in reward mechanisms. *Current Opinion in Neurobiology*, 7(2), 191-197.
- Schultz, W. (1998). Predictive Reward Signal of Dopamine Neurons. *Journal of Neurophysiology*, 80(1), 1-27.

- Schultz, W. (2001). Reward signaling by dopamine neurons. *The Neuroscientist*, 7(4), 293-302.
- Schultz, W. (2006). Behavioural Theories and the Neurophysiology of Reward. *Annual Review of Psychology*, 57(1), 87-115.
- Schultz, W. (2010). Dopamine signals for reward value and risk: Basic and recent data. *Behavioral and Brain Functions*, 6:24.
- Schultz, W., Dayan, P., & Montague, P. R. (1997). A neural substrate of prediction and reward. *Science*, 275, 1593-1599.
- Schultz, W., Tremblay, L., & Hollerman, J. R. (1998). Reward prediction in primate basal ganglia and frontal cortex. *Neuropharmacology*, 37(4-5), 421-429.
- Schupp, H., Junghofer, M., Weike, A., & Hamm, A. (2003). Emotional facilitation of sensory processing in the visual cortex. *Psychological Science*, 14(1), 7 - 13.
- Schupp, H., Ohman, A., Junghofer, M., Weike, A., Stockburger, J., & Hamm, A. (2004). The facilitated processing of threatening faces: An ERP analysis. *Emotion*, 4(2), 189 - 200.
- Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. *Progress in Brain Research, Volume 156*, 31-51.
- Schupp, H. T., Markus, J., Weike, A. I., & Hamm, A. O. (2003). Emotional Facilitation of Sensory Processing in the Visual Cortex. *Psychological Science*, 14(1), 7-13.
- Schupp, H. T., Stockburger, J., Codispoti, M., Junghofer, M., Weike, A. I., & Hamm, A. O. (2007). Selective Visual Attention to Emotion. *Journal of Neuroscience*, 27(5), 1082-1089.
- Schwarz, N. (2000). Emotion, cognition, and decision making. *Cognition and Emotion*, 14(4), 433-440.
- Schwarz, N., & Clore, G. L. (1988). How do I feel about it? Informative functions of affective states. In K. Fiedler & J. Forgas (Eds.) *Affect, Cognition, and Social Behavior* (pp. 44–62). Toronto: Hogrefe International.
- Schweighofer, N., Shishida, K., Han, C. E., Okamoto, Y., Tanaka, S. C., Yamawaki, S., et al. (2006). Humans Can Adopt Optimal Discounting Strategy under Real-Time Constraints. *PLoS Computational Biology*, 2(11), e152.
- Scott, G. G., O'Donnell, P. J., Leuthold, H., & Sereno, S. C. (2009). Early emotion word processing: Evidence from event-related potentials. *Biological Psychology*, 80(1), 95-104.
- Sellitto, M., Ciaramelli, E., & di Pellegrino, G. (2011). The neurobiology of intertemporal choice: insight from imaging and lesion studies. *Reviews in the Neurosciences*, 22(5), 565-574.
- Shafir, E., Simonson, I., & Tversky, A. (1993). Reason-based choice. *Cognition*, 49(1-2), 11-36.

- Shamosh, N. A., DeYoung, C. G., Green, A. E., Reis, D. L., Johnson, M. R., Conway, A. R. A., et al. (2008). Individual Differences in Delay Discounting. *Psychological Science*, 19(9), 904-911.
- Shamosh, N. A., & Gray, J. R. (2008). Delay discounting and intelligence: A meta-analysis. *Intelligence*, 36(4), 289-305.
- Shani, Y., Tykocinski, O. E., & Zeelenberg, M. (2008). When ignorance is not bliss: How feelings of discomfort promote the search for negative information. *Journal of Economic Psychology*, 29(5), 643-653.
- Sharot, T., Riccardi, A. M., Raio, C. M., & Phelps, E. A. (2007). Neural mechanisms mediating optimism bias. *Nature*, 450(7166), 102-105.
- Sharot, T., Velasquez, C. M., & Dolan, R. J. (2010). Do Decisions Shape Preference? *Psychological Science*, -.
- Shelley, M. K. (1994). Gain/Loss Asymmetry in Risky Intertemporal Choice. *Organizational Behavior and Human Decision Processes*, 59(1), 124-159.
- Shimojo, S., Simion, C., Shimojo, E., & Scheier, C. (2003). Gaze bias both reflects and influences preference. *Nature Neuroscience*, 6(12), 1317-1322.
- Shiv, B., Loewenstein, G., & Bechara, A. (2005). The dark side of emotion in decision-making: When individuals with decreased emotional reactions make more advantageous decisions. *Cognitive Brain Research*, 23(1), 85-92.
- Skatova, A., & Ferguson, E. (2011). What makes people cooperate? Individual differences in BAS/BIS predict strategic reciprocation in a public goods game. *Personality and Individual Differences*, 51(3), 237-241.
- Slovic, P., Finucane, M., Peters, E., & MacGregor, D. G. (Eds.). (2002). The affect heuristic. In T. Gilovich, D. Griffin & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment* (pp. 397-420). New York: Cambridge University Press.
- Slovic, P., Fischhoff, B., & Lichtenstein, S. (1984). Behavioral decision theory perspectives on risk and safety. *Acta Psychologica*, 56(1-3), 183-203.
- Small, D. M., Bender, G., Veldhuizen, M. G., Rudenga, K., Nachtigal, D., & Felsted, J. (2007). The Role of the Human Orbitofrontal Cortex in Taste and Flavor Processing. *Annals of the New York Academy of Sciences*, 1121(1), 136-151.
- Small, D. M., Gitelman, D., Simmons, K., Bloise, S. M., Parrish, T., & Mesulam, M. M. (2005). Monetary Incentives Enhance Processing in Brain Regions Mediating Top-down Control of Attention. *Cereb. Cortex*, 15(12), 1855-1865.
- Smillie, L. D., Cooper, A. J., & Pickering, A. D. (2010). Individual differences in reward-prediction-error: extraversion and feedback-related negativity. *Social Cognitive and Affective Neuroscience*.
- Smith, C., & Hantula, D. (2008). Methodological considerations in the study of delay discounting in intertemporal choice: A comparison of tasks and modes. *Behavior Research Methods*, 40(4), 940-953.

- Soane, E., & Chmiel, N. (2005). Are risk preferences consistent?: The influence of decision domain and personality. *Personality and Individual Differences*, 38(8), 1781-1791.
- Solanto, M. V. (1998). Neuropsychopharmacological mechanisms of stimulant drug action in attention-deficit hyperactivity disorder: a review and integration. *Behavioural Brain Research*, 94(1), 127-152.
- Soll, J. B., & Larrick, R. P. (2009). Strategies for Revising Judgment: How (and How Well) People Use Others' Opinions. *Journal of Experimental Psychology: Learning Memory and Cognition*, 35(3), 780-805.
- Soman, D., Ainslie, G., Frederick, S., Li, X., Lynch, J., Moreau, P., et al. (2005). The Psychology of Intertemporal Discounting: Why are Distant Events Valued Differently from Proximal Ones? *Marketing Letters*, 16(3), 347-360.
- Sorrentino, R. M. (2000). *The Uncertain Mind: Individual differences in facing the unknown*. London: Erlbaum.
- Sozou, P. D. (1998). On hyperbolic discounting and uncertain hazard rates. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 265(1409), 2015-2020.
- St Onge, J. R., & Floresco, S. B. (2009). Dopaminergic Modulation of Risk-Based Decision Making. *Neuropsychopharmacology*, 34(3), 681-697.
- Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review*, 28(1), 78-106.
- Stewart, N. (2009). Decision by sampling: The role of the decision environment in risky choice. *The Quarterly Journal of Experimental Psychology*, 62(6), 1041 - 1062.
- Stewart, N., Chater, N., & Brown, G. D. A. (2006). Decision by sampling. *Cognitive Psychology*, 53(1), 1-26.
- Stocco, A., & Fum, D. (2008). Implicit emotional biases in decision making: The case of the Iowa Gambling Task. *Brain and Cognition*, 66(3), 253-259.
- Strathman, A., Gleicher, F., Boninger, D. S., & Edwards, C. S. (1994). The Consideration of Future Consequences: Weighing Immediate and Distant Outcomes of Behavior. *Journal of Personality and Social Psychology*, 66(4), 742-752.
- Studer, B., & Clark, L. (2011). Place your bets: psychophysiological correlates of decision-making under risk. *Cognitive, Affective, & Behavioral Neuroscience*, 11(2), 144-158.
- Suhr, J., & Hammers, D. (2010). Who Fails the Iowa Gambling Test (IGT)? Personality, Neuropsychological, and Near-Infrared Spectroscopy Findings in Healthy Young Controls. *Archives of Clinical Neuropsychology*, 25(4), 293-302.
- Suhr, J. A., & Tsanadis, J. (2007). Affect and personality correlates of the Iowa Gambling Task. *Personality and Individual Differences*, 43(1), 27-36.

- Suls, J., Martin, R., & Wheeler, L. (2002). Social comparison: Why, with whom, and with what effect? *Current Directions in Psychological Science*, 11(5), 159-163.
- Swann, A. C., Bjork, J. M., Moeller, F. G., & Dougherty, D. M. (2002). Two models of impulsivity: relationship to personality traits and psychopathology. *Biol Psychiatry*, 51, 988-994.
- Symmonds, M., Wright, N. D., Bach, D. R., & Dolan, R. J. (2011). Deconstructing risk: Separable encoding of variance and skewness in the brain. *NeuroImage*, 58(4), 1139-1149.
- Takahashi, T., Ikeda, K., & Hasegawa, T. (2007). A hyperbolic decay of subjective probability of obtaining delayed rewards. *Behavioral and Brain Functions*, 3.
- Takahashi, T., Oono, H., & Radford, M. H. B. (2008). Psychophysics of time perception and intertemporal choice models. *Physica A: Statistical Mechanics and its Applications*, 387(8-9), 2066-2074.
- Tenney, E. R., Spellman, B. A., & MacCoun, R. J. (2008). The benefits of knowing what you know (and what you don't): How calibration affects credibility. *Journal of Experimental Social Psychology*, 44(5), 1368-1375.
- Tesch, A., D., & Sanfey, A., G. . (2008). Models and Methods in Delay Discounting. *Annals of the New York Academy of Sciences*, 1128, 90-94.
- Thaler, R. (1981). Some empirical evidence on dynamic inconsistency. *Economics Letters*, 8(3), 201-207.
- Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. [doi: 10.1016/j.actpsy.2010.02.006]. *Acta Psychologica*, 135(2), 77-99.
- Tobler, P. N., Dickinson, A., & Schultz, W. (2003). Coding of predicted reward omission by dopamine neurons in a conditioned inhibition paradigm. *Journal of Neuroscience*, 23, 10402-10410.
- Tobler, P. N., Fiorillo, C. D., & Schultz, W. (2005). Adaptive Coding of Reward Value by Dopamine Neurons. *Science*, 307(5715), 1642-1645.
- Tobler, P. N., O'Doherty, J. P., Dolan, R. J., & Schultz, W. (2007). Reward value coding distinct from risk attitude-related uncertainty coding in human reward systems. *Journal of Neurophysiology*, 97(2), 1621-1632.
- Todorov, A., Goren, A., & Trope, Y. (2007). Probability as a psychological distance: Construal and preferences. *Journal of Experimental Social Psychology*, 43(3), 473-482.
- Tremblay, L., & Schultz, W. (2000). Modifications of reward expectation-related neuronal activity during learning in primate orbitofrontal cortex. *Journal of Neurophysiology*, 83, 1877-1885.
- Trepel, C., Fox, C. R., & Poldrack, R. A. (2005). Prospect theory on the brain? Toward a cognitive neuroscience of decision under risk. *Cognitive Brain Research*, 23(1), 34-50.

- Trommershäuser, J., Maloney, L. T., & Landy, M. S. (2008). Decision making, movement planning and statistical decision theory. *Trends in Cognitive Sciences*, 12(8), 291-297.
- Trope, Y., & Liberman, N. (2003). Temporal Construal. *Psychological Review*, 110(3), 403-421.
- Ungemach, C., Chater, N., & Stewart, N. (2009). Are Probabilities Overweighted or Underweighted When Rare Outcomes Are Experienced (Rarely)? *Psychological Science*, 20(4), 473-479.
- Ungemach, C., Stewart, N., & Reimers, S. (2011). How Incidental Values From the Environment Affect Decisions About Money, Risk, and Delay. *Psychological Science*, 22(2), 253-260.
- Upton, D. J., Bishra, A. J., Ahn, W-Y., & Stout, J. C. (2011). Propensity for risk taking and trait impulsivity in the Iowa Gambling Task. *Personality and Individual Differences*, 50(4), 492-495.
- Upton, D. J., Kerestes, R., & Stout, J. C. (2011). Comparing the Iowa and Soochow gambling tasks in opiate users. *Frontiers in Neuroscience (pending publication)*.
- van den Broek, M. D., Bradshaw, C. M., & Szabadi, E. (1992). Performance of impulsive and non-impulsive subjects on two temporal differentiation tasks. *Personality and Individual Differences*, 13(2), 169-174.
- van Dijk, E., & Zeelenberg, M. (2007). When curiosity killed regret: Avoiding or seeking the unknown in decision-making under uncertainty. *Journal of Experimental Social Psychology*, 43(4), 656-662.
- van Duuren, E., Escamez, F. A. N., Joosten, R., Visser, R., Mulder, A. B., & Pennartz, C. M. A. (2007). Neural coding of reward magnitude in the orbitofrontal cortex of the rat during a five-odor olfactory discrimination task. *Learning & Memory*, 14(6), 446-456.
- van Honk, J. C. A., Hermans, E. J., Putman, P., Montagne, B., & Schutter, D. J. L. G. (2002). Defective somatic markers in sub-clinical psychopathy. *Neuroreport* 13(8), 1025-1027.
- van Son, J., Nykliček, I., Pop, V., & Pouwer, F. (2011). Testing the effectiveness of a mindfulness-based intervention to reduce emotional distress in outpatients with diabetes (DiaMind): design of a randomised controlled trial. *BMC Public Health*, 11(1), 1-11.
- Van Swol, L. M. (2011). Forecasting another's enjoyment versus giving the right answer: Trust, shared values, task effects, and confidence in improving the acceptance of advice. *International Journal of Forecasting*, 27(1), 103-120.
- Villejoubert, G., & Vallée-Tourangeau, F. (2011). Constructing preferences in the physical world: A distributed cognition perspective on preferences and risky choices. *Frontiers in Psychology*, 2:302.

- Voigt, D. C., Dillard, J. P., Braddock, K. H., Anderson, J. W., Sopory, P., & Stephenson, M. T. (2009). BIS/BAS scales and their relationship to risky health behaviours. *Personality and Individual Differences*, 47(2), 89-93.
- Volkow, N. D., Wang, G. J., Telang, F., Fowler, J. S., Thanos, P. K., Logan, J., et al. (2008). Low dopamine striatal D2 receptors are associated with prefrontal metabolism in obese subjects: Possible contributing factors. *Neuroimage*, 42(4), 1537-1543.
- von Neumann, J., & Morgenstern, O. (1944). *Theory of Games and Economic Behavior*. Princeton: Princeton University Press.
- Voorhees, C. M., Baker, J., Bourdeau, B. L., Brocato, E. D., & Cronin, J. J. (2009). It Depends: Moderating the Relationships Among Perceived Waiting Time, Anger, and Regret. *Journal of Service Research*, 12(2), 138-155.
- Vorhold, V., Giessing, C., Wiedemann, P. M., Schütz, H., Gauggel, S., & Fink, G. R. (2007). The neural basis of risk ratings: Evidence from a functional magnetic resonance imaging (fMRI) study. *Neuropsychologia*, 45(14), 3242-3250.
- Vuchinich, R. E., & Simpson, C. A. (1998). Hyperbolic temporal discounting in social drinkers and problem drinkers. *Experimental and Clinical Psychopharmacology*, 6(3), 292-305.
- Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, 9(12), 585 - 594.
- Wächter, T., Lungu, O. V., Liu, T., Willingham, D. T., & Ashe, J. (2009). Differential Effect of Reward and Punishment on Procedural Learning. *The Journal of Neuroscience*, 29(2), 436-443.
- Wade, T. R., de Wit, H., & Richards, J. B. (2000). Effects of dopaminergic drugs on delayed reward as a measure of impulsive behavior in rats. *Psychopharmacology* 150, 90-101.
- Waelti, P., Dickinson, A., & Schultz, W. (2001). Dopamine responses comply with basic assumptions of formal learning theory. *Nature*, 412, 43-48.
- Wallis, J. D., & Miller, E. K. (2003). Neuronal activity in primate dorsolateral and orbital prefrontal cortex during performance of a reward preference task. *European Journal of Neuroscience*, 18(7), 2069-2081.
- Walther, H. (2010). Anomalies in intertemporal choice, time-dependent uncertainty and expected utility - A common approach.. *Journal of Economic Psychology*, 31(1), 114-130.
- Wang, G. J., Volkow, N. D., Thanos, P. K., & Fowler, J. S. (2004). Similarity between obesity and drug addiction as assessed by neurofunctional imaging: a concept review. *Journal of Addictive Diseases*, 23, 39-53.
- Wang, X. T., & Dvorak, R. D. (2010). Sweet future: Fluctuating blood glucose levels affect future discounting. *Psychological Science*, 21(2), 183-188.
- Warren, C., McGraw, A. P., & Van Boven, L. (2011). Values and preferences: defining preference construction. *Cognitive Science*, 2(2), 193-205.

- Watanabe, M. (1996). Reward expectancy in primate prefrontal neurons. *Nature*, 382(6592), 629-632.
- Weatherly, J. N., Derenne, A., & Terrell, H. K. (2011). Testing the reliability of delay discounting of ten commodities using the fill-in-the-blank method. *Psychological Record*, 61(1), 113-126.
- Weatherly, J. N., Terrell, H. K., & Derenne, A. (2010). Delay Discounting of Different Commodities. *The Journal of General Psychology*, 137(3), 273 - 286.
- Weaver, E. A., & Stewart, T. R. (2011). Dimensions of Judgment: Factor Analysis of Individual Differences. *Journal of Behavioral Decision Making*(in Press).
- Weber, B. J., & Chapman, G. B. (2005). The combined effects of risk and time on choice: Does uncertainty eliminate the immediacy effect? Does delay eliminate the certainty effect? *Organizational Behavior and Human Decision Processes*, 96(2), 104-118.
- Weber, B. J., & Huettel, S. A. (2008). The neural substrates of probabilistic and intertemporal decision making. *Brain Research*, 1234, 104-115.
- Weber, E. U., & Johnson, E. J. (2009). Mindful judgment and Decision Making *Annual Review of Psychology* (Vol. 60, pp. 53-85).
- Weber, E. U., Johnson, E. J., Milch, K. F., Chang, H., Brodscholl, J. C., & Goldstein, D. G. (2007). Asymmetric Discounting in Intertemporal Choice: A Query-Theory Account. *Psychological Science*, 18(6), 516-523.
- Weil, R. S., Furl, N., Ruff, C. C., Symmonds, M., Flandin, G., Dolan, R. J., et al. (2010). Rewarding Feedback After Correct Visual Discriminations Has Both General and Specific Influences on Visual Cortex. *Journal of Neurophysiology*, 104(3), 1746-1757.
- Weller, J. A., Levin, I. P., Shiv, B., & Bechara, A. (2007). Neural correlates of adaptive decision making for risky gains and losses. *Psychological Science*, 18(11), 958-964.
- Weller, R. E., Cook, E. W., Avsar, K. B., & Cox, J. E. (2008). Obese women show greater delay discounting than healthy-weight women. *Appetite*, 51(3), 563-569.
- Werthmann, J., Roefs, A., Nederkoorn, C., Mogg, K., Bradley, B. P., & Jansen, A. (2011). Can(not) Take my Eyes off it: Attention Bias for Food in Overweight Participants. *Health Psychology*, 30(5), 561-569.
- Wilson, T. D., & Dunn, E. W. (2004). Self-Knowledge: Its Limits, Value, and Potential for Improvement. *Annual Review of Psychology*, 55(1), 493-518.
- Winstanley, C. A., Theobald, D. E. H., Cardinal, R. N., & Robbins, T. W. (2004). Contrasting roles of basolateral amygdala and orbitofrontal cortex in impulsive choice. *Journal of Neuroscience*, 24(20), 4718-4722.
- Wise, R. A., & Bozarth, M. A. (1981). Brain substrates for reinforcement and drug self-administration. *Progress in Neuro-Psychopharmacology*, 5(5-6), 467-474.

- Wise, R. A., & Rompre, P. P. (1989). Brain dopamine and reward. *Annual Review of Psychology*, 40, 191-225.
- Wittmann, M., Leland, D. S., Churan, J., & Paulus, M. P. (2007). Impaired time perception and motor timing in stimulant-dependent subjects. *Drug and Alcohol Dependence*, 90(2-3), 183-192.
- Wittmann, M., Lovero, K. L., Lane, S. D., & Paulus, M. P. (2010). Now or Later? Striatum and Insula Activation to Immediate Versus Delayed Rewards. *Journal of Neuroscience, Psychology, & Economics*, 3(1), 15-26.
- Wittmann, M., & Paulus, M. P. (2008). Decision making, impulsivity and time perception. *Trends in Cognitive Sciences*, 12(1), 7-12.
- Wittmann, M., & Paulus, M. P. (2009a). Intertemporal Choice: Neuronal and Psychological Determinants of Economic Decisions. *Journal of Neuroscience, Psychology, & Economics November*, 2(2), 71-74.
- Wittmann, M., & Paulus, M. P. (2009b). Temporal Horizons in Decision Making. *Journal of Neuroscience, Psychology, & Economics*, 2(1), 1-11.
- Wout, M. v. t. a. b., Kahn, R. S., Sanfey, A. G., & Aleman, A. c. (2005). Repetitive transcranial magnetic stimulation over the right dorsolateral prefrontal cortex affects strategic decision-making. *Neuroreport November*, 16(16), 1849-1852.
- Wu, S.-W., Delgado, M. R., & Maloney, L. T. (2009). Economic decision-making compared with an equivalent motor task. *Proceedings of the National Academy of Sciences*, 106(15), 6088-6093.
- Wu, Y., & Zhou, X. L. (2009). The P300 and reward valence, magnitude, and expectancy in outcome evaluation. *Brain Research*, 1286, 114-122.
- Yacubian, J., Sommer, T., Schroeder, K., Glascher, J., Braus, D. F., & Buchel, C. (2007). Subregions of the ventral striatum show preferential coding of reward magnitude and probability. *Neuroimage*, 38(3), 557-563.
- Yang, T., & Shadlen, M. N. (2007). Probabilistic reasoning by neurons. *Nature*, 447(7148), 1075-U1072.
- Yaniv, I. (2004a). The Benefit of Additional Opinions. *Current Directions in Psychological Science*, 13(2), 75-78.
- Yaniv, I. (2004b). Receiving other people's advice: Influence and benefit. *Organizational Behavior and Human Decision Processes*, 93(1), 1-13.
- Yaniv, I., & Choshen-Hillel, S. (2011). Exploiting the Wisdom of Others to Make Better Decisions: Suspending Judgment Reduces Egocentrism and Increases Accuracy. *Journal of Behavioral Decision Making*, (in Press).
- Yaniv, I., Choshen-Hillel, S., & Milyavsky, M. (2009). Spurious Consensus and Opinion Revision: Why Might People Be More Confident in Their Less Accurate Judgments? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 25(2), 558-563.

- Yaniv, I., Choshen-Hillel, S., & Milyavsky, M. (2011). Receiving advice on matters of taste: Similarity, majority influence, and taste discrimination. *Organizational Behavior and Human Decision Processes*, 115(1), 111-120.
- Yaniv, I., & Milyavsky, M. (2007). Using advice from multiple sources to revise and improve judgments. *Organizational Behavior and Human Decision Processes*, 103(1), 104-120.
- Yasuno, F., Suhara, T., & Sudo, Y. (2001). Relation among dopamine D2 receptor binding, obesity and personality in normal human subjects. *Neuroscience Letters*, 300, 59-61.
- Yeung, N., Holroyd, C. B., & Cohen, J. D. (2005). ERP Correlates of Feedback and Reward Processing in the Presence and Absence of Response Choice. *Cerebral Cortex*, 15(5), 535-544.
- Yi, R., de la Piedad, X., & Bickel, W. K. (2006). The combined effects of delay and probability in discounting. *Behavioural Processes*, 73(2), 149-155.
- Yu, R. J., Luo, Y. J., Ye, Z., & Zhou, X. L. (2007). Does the FRN in brain potentials reflect motivational/affective consequence of outcome evaluation? *Progress in Natural Science*, 17, 136-143.
- Zacks, R. T., & Hasher, L. (2002). *Frequency processing: A twenty-five year perspective*. New York: Oxford University Press.
- Zauberman, G., Kim, B. K., Malkoc, S. A., & Bettman, J. R. (2009). Discounting Time and Time Discounting: Subjective Time Perception and Intertemporal Preferences. *Journal of Marketing Research*, 46(4), 543-556.
- Zeelenberg, R., Wagenmakers, E., & Rotteveel, M. (2006). The Impact of Emotion on Perception. *Psychological Science*, 17(4), 287-291.
- Zhong, S., Israel, S., Xue, H., Sham, P. C., Ebstein, R. P., & Chew, S. H. (2009). A neurochemical approach to valuation sensitivity over gains and losses. *Proceedings of the Royal Society B: Biological Sciences*, 276(1676), 4181-4188.
- Zimbardo, P. G., & Boyd, J. N. (1999). Putting time in perspective: A valid, reliable individual-differences metric. *Journal of Personality and Social Psychology*, 77(6), 1271-1288.
- Zisseron, R. N., & Palfai, T. P. (2007). Behavioral Activation System (BAS) sensitivity and reactivity to alcohol cues among hazardous drinkers. *Addictive Behaviors*, 32(10), 2178-2186.