An examination of the influence of a fasted state on neurocognitive measures of impulsivity and compulsivity in healthy individuals: Implications for eating disorders research

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I, Maxine Howard confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

Neurocognitive research into eating disorders has suggested that Anorexia Nervosa (AN) has a 'compulsive' profile, characterised by features such as poor cognitive flexibility. Conversely, Bulimia Nervosa (BN) has been linked to increased impulsivity. Chapter 1 systematically examines the literature to show both AN and BN can be conceptualised as sharing elements of impulsivity and compulsivity. The review identified the existing research as inconsistent and inconclusive. Chapter 2 begins to address the question of whether differences in the metabolic state of the participants could account for this inconsistency. Individuals with BN, compared to HCs undergo periods of short-term fasting, and although individuals with BN are matched to Healthy Controls (HCs) for body max index, there is no current marker of fasting. The study reported in Chapter 2 showed that in HCs, 20 hours of fasting significantly alters the expression of impulsivity on two of four neurocognitive measures. Chapter 3 builds on this to investigate compulsivity using the same paradigm, but did not show any influence of fasted state on performance. Chapter 4 describes two studies investigating the relationship between hunger, impulsivity and compulsivity, respectively. The results of Chapter 4 indicated an association between hunger and increased reflection impulsivity, but no link between hunger and other measures of impulsivity, compulsivity or central coherence. Chapter 5 investigates whether the effect of fasting observed in Chapter 2 can be attributed to the types of cues used during these tasks. The study examined whether changes to the physiological state of the individual increases the rewarding and motivational value of food. Results indicate that short-term fasting increased the rewarding value, salience, and interference from food stimuli. Self-reported cravings together with impulsivity independently predicted amount eaten when fasted. Chapter 6 summarizes these findings, the relevance to the fields of eating disorders, limitations and implications for future research.

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1. Chapter One
Eating disorders: Everything and yet nothing to do with food

"[A]n eating disorder provides solutions to one's problems in life and is not simply about food and weight."

Kathryn Hansen: Brain over Binge.

Anorexia nervosa (AN) and bulimia nervosa (BN) are chronic and disabling illnesses. AN and BN are associated with medical complications, increased mortality and reduced quality of life (Mathers, Vos, & Stevenson 1999; De la Rie., et al, 2007; Mitchell & Crow, 2006; Hoek, 2006). Lifetime prevalence is estimated to be between 0.3 and 0.9% for AN, and between 0.9 and 1.5% for BN (Smink, van Hoeken, Hoek, 2012). However, it is likely that this is an underestimate, as both males and members of ethnic minorities are less likely to seek help or disclose symptoms (Solmi, Hatch, Hotopf, Treasure, & Micali, 2014).

A recent report published by the eating disorders charity BEAT in February 2015 examined the health, social, and economic impact of eating disorders (EDs) in the UK (B-EAT, 2015). This report highlighted that on average, the number of individuals being diagnosed with an ED and entering inpatient treatment has increased by 7% each year since 2009. Although the rates of AN and BN have been steady, the incidence of eating disorder not otherwise specified (EDNOS) has increased by 15% in females, and 27% in males, between 2000, and 2009 (Micali, Hagberg, & Peterson et al., 2013, although see Smink et al., 2012 for a discussion of this). It is unclear whether the rise in diagnosis is a true reflection of an increase in the number of cases, or more awareness from health providers, and the public. Awareness of eating disorders in the United Kingdom seems to be increasing. Over the last ten years, searches for AN have risen by over 110%, and searches for BN have risen by 5,000% (Google Trends). The report from BEAT also estimated the annual cost to the NHS as between £3.9 and £4.6 billion; a steep increase from the estimate of £1.26 billion in 2012 (Henderson, 2012). Together these statistics suggest that the awareness, incidence, and cost of EDs are rising; yet treatment outcomes remain poor (Fairburn, 2005). On average, fewer than 50% of those with AN recover, and 20% remain chronically ill, with similar findings for BN (Steinhausen, 2002; Steinhausen, Weber, & Phil, 2009). Longer illness durations in AN are associated with poorer outcomes (Steinhausen, 2002), and physical problems persist after recovery (Bulik et al., 1999; Finfgeld, 2002; Gendall & Bulik, 2005). Klump, Bulik, Kaye, Treasure, & Tyson (2008) highlighted the need for sufficient treatment in order to avoid the serious health consequences and mortality associated with a diagnosis of an eating disorder. Additionally they called for a need to establish parity in the funding, research, and treatment improvement between what they describe as this biologically based serious mental illness (BBMI) and other established BBMIs, such as depression (Klump et al., 2008).

However, developing and improving existing treatments is difficult without a more complete understanding of these illnesses (Fairburn, Cooper, & Shafran, 2003). A review of the current evidence base for the treatment of eating disorders is underway to update the 2004 National Institute for Clinical Excellence (NICE) guidelines. Most of the evidence received a low grade in the 2004 guidelines, indicating that good quality clinical studies were not available to inform practice. The field has progressed since 2004 and the review of these guidelines is a necessary step towards better treatment outcomes. Yet, research into EDs needs to continue to examine the emotional, cognitive, and physiological processes, in a trans-disciplinary manner, in addition to clinical trials, in order to improve treatment (Park, Godier, & Cowdrey, 2014).

1.1 Diagnosis of anorexia and bulimia nervosa

The current system for the diagnosis of an eating disorder is based on observable, or self-reported phenotypes. According to the DSM-5, AN is characterised by a persistent and unrelenting fear of weight gain and a distorted view of body weight and shape. AN involves a difficulty maintaining a minimally normal weight for height and age (American Psychiatric Association, 2013). AN is most frequently observed in females, and typically develops during late adolescence (Patton, Selzer, Coffey, Carlin, & Wolfe, 1999). BN can start after a period of food restriction and develops into frequent cycles of bingeing and compensatory behaviours in an attempt to avoid weight gain (Fairburn, 1995). A binge is characterised as a sense of loss of control over eating an objectively large amount of food in a discrete period of time. Compensatory behaviours can include self-induced vomiting, laxatives, diet pills, exercise, and fasting (American Psychiatric Association, 2013).

Basing diagnosis on visible phenotypes in this way can be an effective method of communicating clinical information (First et al., 2004). Yet, diagnosis and treatment based on observable symptoms may not be the best solution. The current system fails to take into account genetic and developmental factors, which could influence the progression of the illness (Treasure, Lopez, & Roberts, 2007). Of those that have been diagnosed with AN, 55% go on to develop binge purge symptoms (Eddy et al., 2008). Additionally, almost 30% of individuals with BN report a history of AN (Keel & Mitchell, 1997). This shows that individuals can move between diagnostic categories and that symptoms fluctuate over time (Fairburn et al., 2003). In addition, environmental factors may play a part in the trajectory of the illness, and symptom fluctuation (Treasure, Lopez, & Roberts, 2007). As illustrated by the following quote:

> *"Researchers often say that genetics load the 'gun' of eating disorders, and environment 'pulls the trigger'… It seems to me that genetics makes the gun, and cultural and familial environment loads it, but it takes the experience of unbearable emotion to pull the trigger."*
>
> \- Aimee Liu, Gaining: The Truth about Life After Eating Disorders

In recent years there has been a shift away from research in the eating disorders field based on these unstable diagnostic categories (Anderluh et al., 2009), towards research involving neuropsychology (Roberts, Tchanturia, & Treasure, 2010). By examining brain-behaviour relationships, it is hoped that the aetiology and maintenance of EDs can be better understood. It is thought that some of the behaviours exhibited in the EDs could be underpinned by alterations in cognitive functioning (Tchanturia, Davies, Roberts, Harrison, Nakazato, Schmidt, Treasure, & Morris, 2012). For example it has been proposed that the rigid, and inflexible behaviours observed in those with AN, such as counting calories, and ritualistic eating could be related to alterations in executive functioning.

1.2. Cognitive processing in anorexia nervosa

Researchers have often made comparisons between the clinical features of AN, such as rigidity in eating behaviour, and the behaviour displayed in obsessive-compulsive disorder (Serpell, Hirani, Willoughby, Neiderman & Lask, 2006; Serpell, Livingstone, Neiderman, & Lask, 2002, Shafran, 2002; Tyagi, Patel, Rughooputh, Abrahams, Watson, & Drummond, 2015). Individuals with a lifetime history of AN score higher on measures of compulsivity than healthy controls (HCs) (Holliday, Uher, Landau, Collier,

& Treasure, 2006). Additionally, individuals with AN retrospectively report the presence of obsessive-compulsive features prior to the onset of AN (Brecelj, Anderluh, Tchanturia, Rabe-Hesketh, & Treasure, 2003). This suggests that the compulsive behaviours may not simply be related to the acute phase of the illness, and may be a trait characteristic that contributes to the aetiology of AN. Treasure (2007) suggests that these obsessive-compulsive behaviours are underpinned by trait alterations in cognitive functioning, and information processing styles. Exploring these deficits in cognition could lead to candidate endophenotypes.

1.3. Endophenotypes in eating disorder research

Endophenotypes reflect heritable enduring characteristics, which are independent of the state of the individual. Therefore, the characteristic will be present both prior to the development of the ED and after recovery. The characteristic should also be more likely to be found in non-affected family members, compared to the general population (Gottesman & Gould, 2003). Treasure, Lopez, and Roberts (2007) have recommended a biologically based classification system, using endophenotypes to diagnose and guide treatment recommendations. It is hoped that establishing potential endophenotypes will help to identify individuals at risk of developing an ED, as well as allowing the development of tailored treatments and this improved outcomes (Treasure, Lopez, & Roberts, 2007).

Research examining endophenotypes in AN is more advanced compared to BN, and has identified cognitive flexibility as a potential candidate. Individuals with AN are commonly shown to be rigid in behaviour and thinking style, perseverative, and inflexible when compared to healthy controls (Vitousek, & Manke 1994; Walter, 2008). This has been suggested to underpin co-morbid obsessive-compulsive disorder, and anxiety present in AN (Anderluh, Tchanturia, Rabe-Hesketh, Collier & Treaure, 2009; Godart, Flament, Lecrubier, & Jeammet, 2000; Harrison, O'Brien, Lopez, & Treasure, 2010). Specifically, research has identified difficulties in set shifting - the ability to move back and forth between different stimuli or 'mental' sets (Holliday, Tchanturia, Landau, Collier, & Treasure, 2005). This index of cognitive inflexibility has been observed in those recovered from AN, and to some extent, BN (Roberts, Tchanturia, Stahl, Southgate, & Treasure, 2007; Roberts, Tchanturia, & Treasure, 2010), in addition to unaffected sisters of those with AN (Holliday et al., 2005).

A further aspect of executive functioning that has been suggested as a potential endophenotype is central coherence. Weak central coherence has been defined as 'a cognitive style in which there is a bias towards local or detailed processing of information over the natural tendency to integrate information into a context' (Lopez Tchanturia, Stahl, Booth, Holliday, & Treasure, 2008; Happe, & Frith, 2006). Lopez, Tchanturia, Stahl, & Treasure (2008a) describe individuals with AN and BN as having poorer performance on tasks measuring global processing, in comparison to HCs. In addition, Lopez, Tchanturia, Stahl, & Treasure (2008) reported superior detailed processing in those with AN. However, the extent to which this represents a distinct endophenotype i.e. not related to the state of the illness has been debated (Lopez, Tchanturia, Stahl, & Treasure 2008; Talbot, Hay, Buckett, & Touyz, 2015).

1.4. Compulsivity in anorexia nervosa

Compulsivity has been defined as *'actions inappropriate to the situation which persist, have no obvious relationship to the overall goal and which often result in undesirable consequences'* (Dalley, Everitt, & Robbins, 2011). However, a distinction can be made between the behavioural and cognitive view of compulsivity. Dysregulation of the cognitive systems that mediate compulsivity can be measured through impaired performance on cognitive tasks as a result of perseverative errors and an inability to switch sets. Evidence of this decreased cognitive flexibility (Roberts, et al, 2007) and disrupted decision making (Lopez et al., 2008) in AN has led to the conceptualisation of AN as compulsive in nature (Godier & Park, 2014). However, there is also evidence of behavioural expressions of compulsivity such as extreme food restriction and compulsive exercise (Dalle Grave et al., 2008). The compulsive actions performed by individuals with AN are often repetitive and stereotyped. During the course of AN, the behavioural repertoire narrows and compulsive behaviour, such as ritualistic eating and exercise, become more apparent and problematic (Godier, & Park, 2014), suggesting that starvation may at least exacerbate compulsivity once the ED is established.

1.5. Impulsivity in bulimia nervosa

Conversely, BN has been described as a disorder of poor impulse control. The loss of control shown during binge eating and purging has been related to an inability to inhibit actions (Boisseau, Thompson-Brenner, Eddy, & Satir, 2009; Claes, Vandereycken, & Vertommen, 2001; Fernandez-Aranda, et al., 2009). Evidence comparing BN and HCs supports this view, showing increased impulsivity in BN compared to non-eating disordered individuals (Mobbs et al, 2008; Rosval et al, 2006; Claes et al, 2005; Freeman et al, 1993).

Whilst definitions of impulsivity vary, one classic definition of impulsivity defines the construct as *‘actions which are poorly conceived, prematurely expressed, unduly risky or inappropriate to the situation and that often result in undesirable consequences’* (Daruna & Barnes, 1993). This definition suggests that the construct of impulsivity encompasses behaviour enacted before the individual has sufficiently sampled all available evidence, (reflection impulsivity); a deficit inhibiting actions, (impulsive action); a tendency to make risky decisions (risky decision-making); and a preference for smaller rewards, sooner vs. larger rewards, later (choice impulsivity), as described by Evenden, (1999). The behavioural expression of these different types of impulsivity is therefore complex and cannot be measured using a single task or self-report measure.

It is hoped that the investigation of whether these traits represent distinct endophenotypes will aid in the identification of individuals at risk, treatment development, and more accurate diagnosis. Research examining the rigid, compulsive nature of AN has already been translated into therapy. Cognitive Remediation Therapy (CRT) targets the behavioural rigidity underpinned by the endophenotype of poor cognitive flexibility. Exercises during therapy are designed to target, and widen the individual's narrow, and rigid information processing style. CRT has been shown to enhance the effectiveness of existing treatments, increase quality of life, and reduce eating disorder psychopathology (Dahlgren & Ro, 2014).

Therapies have also been designed to target the trait of increased impulsivity seen in individuals with BN, such as dialectical behaviour therapy (DBT) (Safer, Telch, & Agras, 2001). There is preliminary evidence that DBT can be effective for BN (Safer, Telch & Agras, 2001; Hill, Craighead & Safer, 2011) . Although the trait of impulsivity has yet to be established as an endophenotype, understanding the neurocognitive profile of individuals with BN may improve the understanding of treatment outcomes, similar to AN, addictions, and schizophrenia (Cavedini, Zorzi, Bassi., et al, 2006; Passetti, Clark, Mehta, Joyce, & King, 2008; Tabares-Seisdedos, Balanza-Martinez, Sanchez-

Moreno., et al, 2008). Neurocognitive performance of individuals with BN could also be used to understand the aetiology of the illness (Steiger, & Bruce, 2007).

1.6. The transdiagnostic model of eating disorders

The existing research base has been taken to indicate that AN and BN are diametrically opposed and lie at either ends of an impulsive/compulsive spectrum (Butler, & Montgomery, 2005). Yet, research has also shown that some elements of impulsivity and compulsivity can co-occur within the same individual. Furthermore, some studies of impulsivity and compulsivity in EDs have shown contradictory findings, e.g. indicating elevated impulsivity in AN. For example Seed, Dixon, McCluskey, and Young (2000) showed that individuals with AN made more errors of commission, indicating increased impulsiveness when compared to HCs. Additionally, the transdiagnostic model put forward by Fairburn (2003) suggests instead that the different eating disorder diagnoses have much in common and share the similar behaviours and underlying maintaining factors, such as the over-evaluation of shape and weight. The transdiagnostic approach proposes that both AN and BN share the same basic psychopathology, which is expressed in similar behaviours such as impulsivity and compulsivity. Differences between AN and BN are then expressed in the domain of under- and over- eating. The frequency with which individuals migrate from one eating disorder diagnosis to another, most often from AN to BN, appears consistent with this view (Agras, Walsh, Fairburn, Wilson & Kraemer, 2000). Fairburn (2003) claims that, as individuals move from AN to BN, the core psychopathology related to shape and weight remains the same. However, as the weight increases, the symptoms of starvation, such as the compulsive rigidity, decrease. The behavioural expression is then in line with that of BN.

Therefore, instead of the traditional view of BN as a disorder of impulsivity, and AN as a disorder of compulsivity these constructs may overlap within the same individual (Robbins, Gillan, Smith, de Wit, & Ersche, 2012). Robbins et al., (2012) has recommended that impulsivity and compulsivity should also be considered transdiagnostically in order to aid the development of novel treatments. Specifically, they recommended that research should focus on cross-diagnostic behaviours, rather than focusing on specific diagnoses. This is in line with the recent Research Domain Criteria (RDoC) strategy approved and used by the National Institute of Mental Health (NIMH). This strategy outlines the need to focus research on constructs, or behaviours, common across psychiatric disorders, in particular those with neurobiological underpinnings (Godier, & Park, 2014).

1.7. Systematic review rationale

However, to date, there have been few studies looking at the co-occurrence of impulsivity and compulsivity across EDs. Although research has examined impulsivity in BN, most of these studies have not included individuals with AN, nor have they included measures of compulsivity. Additionally, the extent to which impulsivity and compulsivity may co-occur across AN and BN is not known. Therefore a necessary step before concluding that these constructs represent distinct endophenotypes and are associated with each eating disorder, is to synthesise and review the existing evidence in order to provide a better understanding of the concepts of impulsivity and compulsivity and their role in AN and BN.

Existing reviews in the area have been limited by focusing solely on BN, examining just impulsivity or overall neurocognitive profile (Waxman, 2009; Van den Eynde et al., 2011). Although Wu, Hartmann, Skunde, Herzog, and Friederich, (2013) conducted a meta-analysis looking trans-diagnostically at AN and BN, this was limited to only one facet of impulsivity; inhibitory control. The meta-analysis completed by Kakzanis, Campbell, and Polsinelli, (2010) only included studies up to 2008, and was not focused on the traits of impulsivity and compulsivity. An updated and more focused review is clearly warranted, in particular in the light of RDoc recommendations and the recent increased interest in neurocognition and the role of possible endophenotypes in eating disorders.

1.7.1. Objectives

The overall objective of the review is to provide an up to date synthesis of the research on the traits of impulsivity and compulsivity, in AN and BN, within the same review. A further aim is to examine whether these traits are trans-diagnostic, and observed in both BN and AN. Finally, the review aims to evaluate the extent to which these traits can be considered as potential endophenotypes.

Specifically, the aim of this review is to systematically appraise evidence that compares the cognitive performance on measures of impulsivity and compulsivity between individuals in the acute phase of BN and/or AN, to HCs. Other eating disorder diagnoses such as BED and EDNOS/OSFED are not included in the review, due to the lack of published studies covering these diagnoses.

1.7.2. Method

This review follows guidelines set out by the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analysis) statement, (Liberati, Altman, Tetzlaff, Mulrow, Gotzsche, & Ioannidid, 2009).

Definition of terms

Impulsivity

The term impulsivity has been used to describe a variety of behaviours, and the precise definition of impulsivity remains difficult due to the multi-faceted nature of the concept, (Waxman, 2009). Researchers have often investigated a variety of behaviours labelled as impulsive, and utilised multiple definitions (Evenden, 1999). Therefore for the purpose of clarity, the definition of impulsivity provided by Daruna and Barnes (1993) will be used in the current review *'actions which are poorly conceived, prematurely expressed, unduly risky or inappropriate to the situation and that often result in undesirable consequences'*.

Compulsivity

The definition of compulsivity provided by Dalley, Everitt, and Robbins (2011) will be used in the current review *'actions inappropriate to the situation which persist, have no obvious relationship to the overall goal and which often result in undesirable consequences'*. This included aspects of compulsivity such as attentional set-shifting, perceptual set-shifting and reversal learning. It is important to note that this definition of compulsivity does not include deficits in central coherence, nor performance on broad measures of executive functioning, as central coherence has been the subject of a very recent systematic review (Lopez et al, 2015), and the inclusion of broad measures of executive functioning is beyond the scope of the current review.

Search procedure

The electronic databases Pubmed, Medline, and PsychInfo were searched using the following terms: ("eating disorder" or "eating disorders" or bulimi* or anorexi*) and (impulsiv* or compulsi* or disinhib* or "loss of control" or persever* or rigid* or "cognitive inflexibility"). A filter was then applied so that only research articles reporting on human subjects were displayed. The reference lists of identified studies and relevant review papers were then examined for any additional references not identified in the electronic search. The breakdown and flow of the search strategy is presented in Figure 1.

Inclusion/exclusion criteria

Empirical studies that met the following criteria were included:

(1) were published in English in a peer reviewed journal

(2) reporting on a behavioural measure of impulsivity or compulsivity

(3) in those aged 18 or above,

(4) with a current diagnosis of bulimia nervosa or anorexia nervosa according to DSM-III or -IV (Diagnostic and Statistical Manual of Mental Disorders) or ICD-9 or -10 (International Statistical Classification of Diseases and Related Health Problems International Classification) criteria

(5) with a comparison group of $\geq$ 10 individuals.

Studies published prior to 2005 were not included in order to best reflect current methods and definitions. Papers that did not report statistical comparisons between groups were not included. In addition studies reporting results from individuals with sub-clinical eating disorders, a mixed eating disorder group, or without a formal diagnosis of an eating disorder according to DSM or ICD criteria were excluded. Studies investigating binge eating disorder were not included as this was not included as a formal diagnosis until DSM-5. Studies of EDNOS/OSFED were not included as this was beyond the scope of the current review. Duplicate publications were also excluded from any further analysis.

During the first stage of screening the title and abstracts of identified articles were examined according to the a priori defined inclusion- and exclusion- criteria. Where this provided insufficient information for assessment against the criteria, stage two involved obtaining and screening full text articles. This was done independently by the candidate and another reviewer, with moderate to good inter-rater reliability ($\kappa = 0.73$). Studies for which there were disagreements or uncertain decisions were re-evaluated by the candidate's primary supervisor.

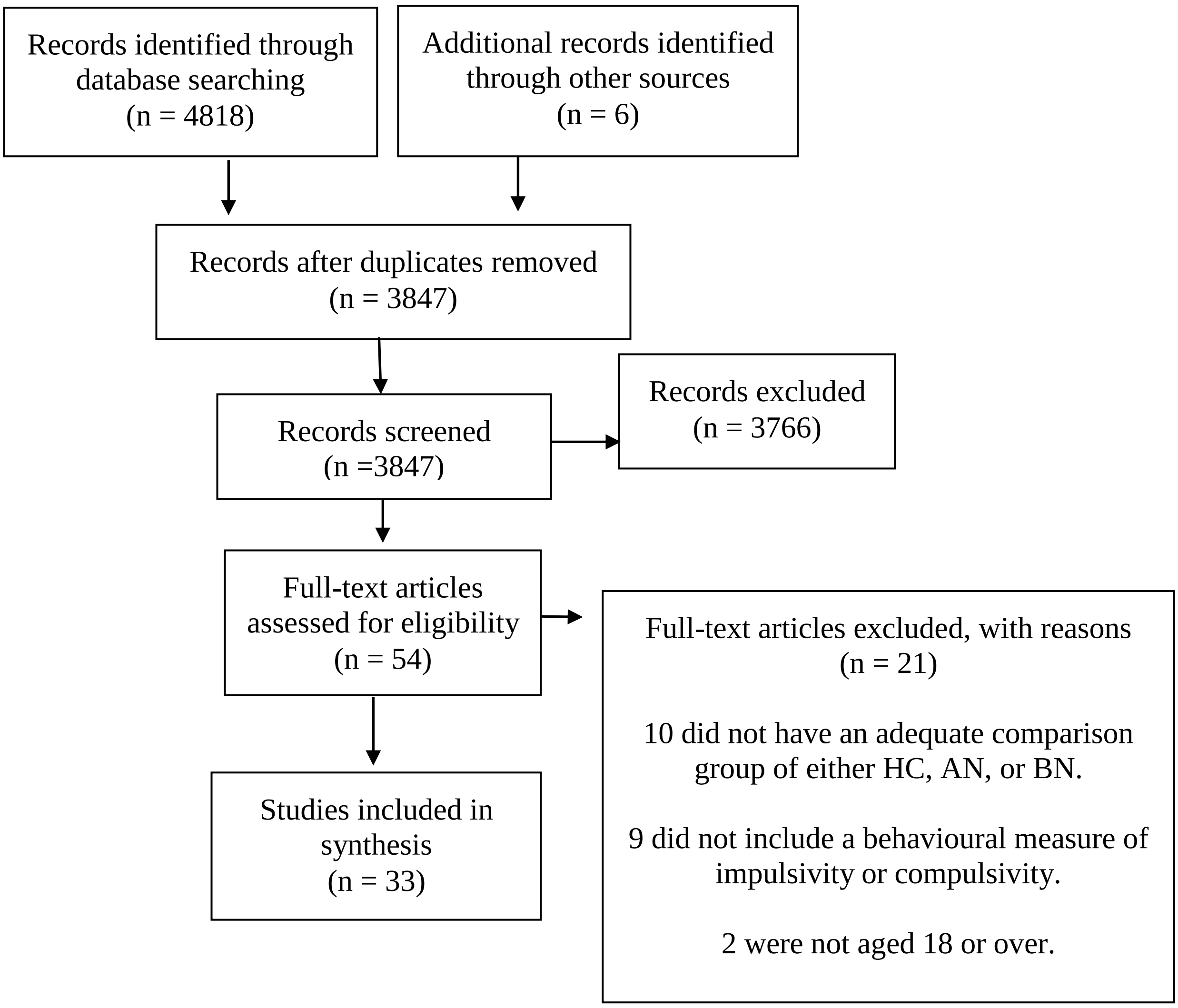


Figure 1. PRISMA flow diagram

Quality Assessment of Included Studies

The methodological quality of included studies was assessed according to the STROBE statement (see Table 1). The STROBE checklist (see Appendix) consists of 22 items that assess the quality of scientific articles. The checklist was used to calculate the percentage of STROBE criteria met by each article (known as the STROBE score). These scores are presented in Table 1, in descending order. Overall quality assessment from A-C was used in place of a sum score, (Jüni, Altman & Egger, 2001). This method has been used in previous reviews, (Olmos, Antelo, Vazquez, Smecuol, Maunno, & Bai, 2008; German, Teti, Rebok, Rojas, Grendas, & Daray, 2014). The three categories of global quality assessment were as follows: (A) the study fulfilled more than 80% of STROBE criteria, (B) the study met between 50–80% of STROBE criteria, or (C) the study met less than 50% of STROBE criteria.

TABLE 1. Percentage of STROBE[a] quality criteria met ("STROBE score") for 34 studies included in the systematic review, ordered by STROBE score

First Author (Date)	STROBE Score (%)	Overall Quality Assessment[b]
Tchanturia et al. (2011)	81%	A
Abbate-Daga et al. (2011)	77%	B
Marsh et al. (2009)	77%	B
Lopez et al. (2008)	72%	B
Holliday et al. (2005)	72%	B
Roberts et al. (2010)	72%	B
Adoue et al. (2015)	68%	B
Southgate et al. (2008)	68%	B
Tchanturia et al. (2012)	68%	B
Friederich et al. (2012)	68%	B
Nakazato et al. (2009)	68%	B
Tchanturia et al. (2012)	68%	B
Aloi et al. (2015)	63%	B
Brand et al. (2007)	63%	B
Fagundo et al. (2012)	63%	B

Mobbs et al. (2008)	63%	B
Roberts et al. (2011)	63%	B
Sherman et al. (2006)	63%	B
Van den Eynde et al. (2011)	63%	B
Galderisi et al. (2011)	63%	B
Zastrow et al. (2009)	63%	B
Brogan et al. (2010)	59%	B
Galimberti et al. (2012)	59%	B
Danner et al. (2012)	54%	B
Liao et al. (2009)	54%	B
Talbot et al. (2015)	54%	B
Abbate-Daga et al. (2014)	50%	B
Camacho Ruiz et al. (2008)	50%	B
Claes et al. (2006)	50%	B
Pignatti et al. (2013)	50%	B
Butler et al. (2005)	45%	C
Kemps et al. (2010)	45%	C
Boisseau et al. (2012)	40%	C
Rosval et al. (2006)	36%	C

[a]Strengthening the Reporting of Observational Studies in Epidemiology[(10)]
[b]Scale of A–C.

1.7.3. Results

Thirty-three studies comparing individuals with AN, BN and HCs on measures of impulsivity and/or compulsivity (Table 2) met the inclusion criteria. See Fig 1 for number of studies included and excluded at each stage of the review. Table 2 provides data on participant characteristics, and tasks used.

The main observations were as follows: (1) Sample sizes tended to be small, and only four out of the 33 studies conducted power calculations to estimate required sample size (Abbate-Daga et al., 20011; Roberts et al., 2010; Roberts et al., 2011; Van den Eynde et al., 2012). The median size and range for each sample was as follows: AN = 38 (10 –

215), BN = 33 (12 – 83), and HCs = 49 (13 – 216). (2) The outcome measures and methods of assessment varied across studies. (3) The majority of studies (*N*= 25), were conducted in Europe, and all were conducted in first world countries. (4) Studies mainly included only female (*N*= 31) participants. (5) Of the 33 included studies, 12 compared AN to HCs, 7 compared BN to HCs, and 14 studies included comparisons between AN, BN, and HCs.

Results are presented separately for the different facets of impulsivity and compulsivity, beginning with a description of the tasks commonly used to measure each facet. This is in line with previous reviews that have reported findings according to different neurocognitive constructs (Zakzanis, Cambell, & Polsinella, 2010; Duchesne, Mattos, Fontenelle, Veiga, Rizo, & Appolinario, 2004).

Firstly, the findings for the different neurocognitive domains of impulsivity are presented in the following order: action inhibition, action restraint, action cancelation, interference control/verbal inhibition, risk taking, and planning. Secondly, findings for the different cognitive domains of compulsivity are presented in the following order: attentional set-shifting, perceptual set-shifting, reversal learning, and tasks that measure both attentional set-shifting and reversal learning. Where a task is hypothesised to measure more than one construct, such as the WCST (inhibition and set-shifting), placement in a specific domain is arbitrary and findings should still be considered as applying to more than one construct. See Fig 2 for a diagram to show the overlapping subcomponents of impulsivity and compulsivity presented in this review (based on Robbins et al, 2012).

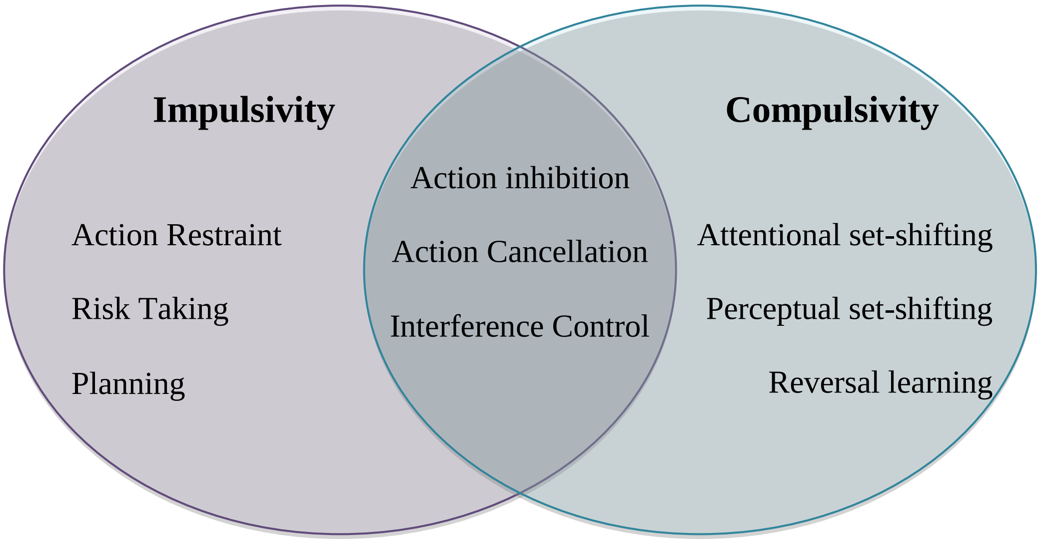


Figure 2. Diagram to illustrate the overlapping constructs of impulsivity and compulsivity. Adapted from Robbins, Gillan, Smith, de Wit, & Ersche (2012)

Table 2. Data extraction table.

Author & Date	Country	Participants	Gender	Age	BMI	Neurocognitive Task
Abbate-Daga et al. (2011)	Italy	AN-R = 30 HC = 30	F	24.13 ± 6.16 24.67 ± 2.64	15.62 ± 1.66 21.04 ± 2.18	WCST[1] IGT[2] TMT[3] HSCT[4]
Abbate-Daga et al. (2014)	Italy	AN = 94 HC = 59	F	24.74 ± 7.25 25.08 ± 3.23	15.17 ± 1.98 20.64 ± 2.01	WCST[1]
Adoue et al. (2015)	France	AN = 63 HC = 49	F	30.3 ± 11.2 24.8 ± 7.1	15.8 ± 2.0 13.6 ± 2.3	IGT[2] BART[5] PRLT[6]
Aloi et al. (2015)	Italy	AN = 45 HC = 45	F	22.8 ± 5.6 25.6 ± 3.5	15.5 ± 1.4 20.2 ± 1.6	IGT[2] TMT[3] WCST[1] HSCT[4]
Boisseau et al. (2012)	USA	HC = 21 BN = 12	F	24.24 ± 3.47 23.48 ± 4.37	22.22 ± 2.28 22.30 ± 3.75	SS[7]
Brand et al. (2007)	Germany	BN = 14 HC =14	F	21.86 ± 3.30 21.64 ± 2.90	21.57 ± 3.84 21.33 ± 2.30	GDT[8] Colour-Word Interference

						TMT[3] Nelson's Modified CST[9] TOL[10] ROCFT[11]
Brogan et al. (2010)	Italy	HC = 20 AN = 22 BN = 17	F	27.27 ± 6.99 29.09 ± 7.36 29.94 ± 6.41	21.55 ± 1.42 16.03 ± 2.04 31.87 ± 9.42	IGT[2]
Butler et al. (2005)	UK	AN = 15 HC = 16	F	27.9 ± 9.9 28.4 ± 8.3	Not Reported 22.75	Bets-16 Continuous Performance Test
Camacho Ruiz et al. (2008)	Mexico	BN = 26 AN = 10 HC = 36	F	Not Reported	Not Reported	WCST[1] Stroop ROCT[11] TOL[10]
Claes et al. (2006)	Germany	AN-R = 20 AN-P = 14 BN = 22 HC = 83	F	23.0 ± 6.6 21.7 ± 6.8 22.7 ± 5.8 20.1 ± 3.1	Not Reported	Stop-go Task
Danner et al. (2012)		AN = 16 HC = 15	F	25.63 ± 5.41 25.80 ± 4.69	14.65 ± 1.7 21.46 ± 2.29	Bergs CST[12] ROCFT[11] IGT[2]

Fagundo et al. (2012)	Spain	AN = 35 HC = 137	F	28.1 ± 8.2 24.8 ± 7.0	17.2 ± 1.4 21.5 ± 2.7	Stroop IGT[2] WCST[1]
Friederich et al. (2012)		AN = 12 HC = 14	F	24.3 ± 6.2 25.6 ± 3.7	15.9 ± 1.6 21.1 ± 1.5	Visual Target Detection
Galderisi et al. (2011)	Italy	BN = 83 HC = 77	F	24.0 ± 4.3 23.8 ± 3.4	21.5 ± 3.7 21.5 ± 2.6	WCST[1]
Galimberti et al. (2012)	Italy	AN-R = 24 AN-B = 12 BN = 16 HC = 40	F	26.70 ± 9.58 27.08 ± 8.86 25.31 ± 5.79 25.95 ± 8.41	14.26 ± 1.21 15.05 ± 1.55 20.43 ± 3.65 19.21 ± 1.57	SS[7] ID-ED Set Shifting
Holliday et al. (2005)	UK	AN = 47 HC = 47	F	26.3 ± 10.2 26.5 ± 6.1	17.9 ± 2.7 22.1 ± 2.3	TMT[3]
Kemps et al. (2010)	Australia	BN = 13 HC = 13	F	22.17 ± 3.88 20.76 ± 3.39	23.61 ± 2.61 22.42 ± 3.35	Stroop HSCT[4] MFFT[13]
Liao et al. (2009)	UK	BN = 26 HC = 51 AN = 29	F	27.8 ± 6.1 29.4 ± 9.6 28.5 ± 9.17	25.3 ± 4.7 23.1 ± 3.9 15.5 ± 1.3	IGT[2]

Lopez et al. (2008)	UK	BN = 42 HC = 42 AN = 42	F	27.0 ± 7.2 26.3 ± 6.4	21.7 ± 2.4 21.9 ± 2.7	ROCFT[11]
Marsh et al. (2009)	USA	BN = 20 HC = 20	F	25.7 ± 7.0 26.35 ± 5.7	22.92 ± 2.3 22.24 ± 2.2	Simon Spatial Incompatibility Task
Mobbs et al. (2008)	Switzerland	BN = 18 HC = 18	F	25.11 ± 3.88 24.28 ± 3.36	20.38 ± 2.61 21.02 ± 1.64	Affective Shifting Task
Nakazato et al. (2009)	UK	AN = 29 HC = 28	F	28.3 ± 11.0 26.9 ± 5.8	15.6 ± 1.6 22.3 ± 2.5	WCST[1]
Pignatti et al. (2013)	Italy	AN = 23 BN = 17 HC = 20	F	29.1 ± 7.4 29.9 ± 6.4 27.8 ± 7.0	16.0 ± 2.0 31.9 ± 9.4 21.6 ± 1.6	HSCT[4] TMT[3] WCST[1]
Roberts et al. (2010)	UK	ANR = 35 ANBP = 33	F	23.71 ± 6.39 25.58 ± 7.64	17.98 ± 2.18 17.88 ± 3.0	TMT[3] WCST[1]
		BN = 30 HC = 88		26.43 ± 6.84 28.43 ± 8.47	21.66 ± 2.94 22.07 ± 1.79	Brixton Haptic Illusions

Roberts et al. (2011)	UK	AN = 35 AN-B = 33 BN = 30 HC = 88	F	23.71 ± 6.39 25.58 ± 7.64 26.43 ± 6.84 28.43 ± 8.43	17.98 ± 2.18 17.88 ± 3.00 21.66 ± 2.94 22.07 ± 1.79	Group Embedded Fig. Test ROCFT[11]
Rosval et al. (2006)	Canada	BN = 79 ANBP = 17 ANR = 18 HC = 59	F	25.04 ± 6.42 25.59 ± 7.71 24.56 ± 10.21 24.32 ± 6.19	21.30 ± 1.91 16.66 ± 1.67 17.13 ± 1.52 21.93 ± 2.22	Go/No-Go Task
Sherman et al. (2006)	USA	AN = 18 HC = 19	F	25.56 ± 5.8 25.68 ± 5.3	16.68 ± 1.1 22.22 ± 1.8	ROCFT[11]
Southgate et al. (2008)	UK	HC = 26 AN = 20 BN = 14	F	27.27 ± 11.52 26.80 ± 8.49 25.71 ± 4.94	21.95 ± 3.42 16.31 ± 2.64 21.12 ± 6.67	MFFT[13]
Talbot et al. (2015)	Australia	AN = 24 HC = 43	Mixed	21.0 21.5	14.99 ± 1.83 21.81 ± 1.48	ROCFT[11] MFFT[13] WCST[1]
Tchanturia et al. (2012)	UK	AN = 171 BN = 82	F	25.4 ± 8.2 27.3 ± 8.3	15.2 ± 1.9 21.3 ± 2.4	WCST[1]

		HC = 199		27.7 ± 8.8	21.9 ± 1.9	
Tchanturia et al. (2011)	UK	HC = 216 AN = 215 BN = 69	F	27.0 ± 7.9 26.9 ± 8.2 27.7 ± 7.8	21.9 ± 1.8 15.0 ± 1.7 21.0 ± 2.1	Brixton
Tchanturia et al. (2012)	UK & Spain	AN = 19 AN = 29 HC = 20 HC = 41	M F M F	27.22 ± 8.54 27.52 ± 7. 49 25.42 ± 7.63 22.2 ± 5.68	17.49 ± 2.64 16.59 ± 1.20 23.54 ± 3.78 22.1 ± 3.94	IGT[2]
Van den Eynde et al. (2011)	UK	HC = 65 BN = 40	F	24.0 ± 2.6 28.3 ± 8.1	22.2 ± 3.3 25.2 ± 7.2	Stroop Go/No-Go GDT[8]
Zastrow et al. (2009)	Germany	AN = 15 HC = 15	F	24.2 ± 2.3 23.1 ± 3.6	15.7 ± 1.7 21.2 ± 1.3	Visual Target Detection

Task abbreviations: [1]Wisconsin Card Sorting Task, [2]Iowa Gambling Task, [3]Trail Making Task, [4]Hayling Sentence Completion Task, [5]Balloon Analogue Risk Task, [6]Probabilistic Reversal Learning Task, [7]Stop Signal Task, [8]Game of Dice Task, [9]Nelsons Modified Card Sorting Task, [10]Tower of London/Hanoi, [11]Rey-Osterrieth Complex Figures Task, [12]Bergs Card Sorting Task, [13]Matching Familiar Figures Test.

1.7.3.1. Impulsivity

Action Inhibition

The term action inhibition describes the prevention of a planned physical response, and a deficit in this ability has been used as a behavioural estimate of impulsivity (Eagle, Bari, & Robbins, 2008). This process has been measured using a variety of behavioural tasks, such as the Go/NoGo task and the Stop Signal Reaction Time Task (Logan, 1994). However, these tasks can be used to measure a variety of outcomes (such as errors and response times to different targets), which have been used as evidence of slightly different sub-constructs of action inhibition (Dalley, Everitt, & Robbins, 2011). Schachar et al. (2007) differentiated between action restraint; the ability to withhold a response tendency and action cancellation; the ability to cancel a pre-planned action. Studies investigating the different components of inhibition are discussed separately below.

Action Restraint

The Go/NoGo task assesses the capacity for stimulus discrimination and action restraint. Participants are told that there will be a series of rapidly presented stimuli, which will either be target items or distractors. Participants are required to manually respond to target words, and withhold responses to distractor stimuli (Murphy et al., 1999). The outcome measures from this task are the time taken to respond (response times), incorrect responses to distractor stimuli (commission errors), and failures to appropriately respond to target stimuli (omission errors). Commission errors are hypothesised to be maximally sensitive to deficits of action restraint (Rosval et al., 2006).

Two studies have used the Go/NoGo task to assess problems of action restraint. One study used a Go/NoGo task with monetary reward and punishment (Rosval et al., 2006) and one without (Van den Eynde et al., 2012). Both studies showed no differences between groups on errors of omission. Van den Eynde et al. (2012) showed no differences between individuals with BN compared to HC on total commission errors; indicating no difference in action restraint. Similarly, Rosval et al. (2006) demonstrated no differences between groups (AN, BN, & HC) for total commission errors.

Another variant of the Go/NoGo task that measures action restraint is the Affective Shifting task (AFT). The AFT differs from the Go/NoGo task as the block order is arranged to provide an additional measure of flexibility in shifting from responding to one set of instructions versus another. In addition, affective or personally relevant stimuli (such as food or body words) are used to examine any potential attentional biases. Therefore the outcome measures assess both action restraint, and interference control. Only one study examined the difference between individuals with BN and HC using the AFT (Mobbs, Van der Linden, d'Acremont, & Perroud, 2008). In this particular version of the AFT, food and body words were used as stimuli. Overall there were no group differences between BN and HCs for total RTs, or for either body or food RTs. However individuals with BN had lower discrimination ability, showing a lower proportion of hits to false alarms, but an overall higher number of hits and false alarms indicating a difficulty with action restraint. Specifically, individuals with BN had a higher number of hits and false alarms for food words only, suggesting a food specific action restraint impairment. No other significant between group differences were found, including measures of interference control/shifting ability.

Action Cancellation

The Stop Signal Task (SST) largely assesses action cancellation. During this task participants are instructed to respond as quickly as possible to a reaction time task. However, on a percentage of trials the participant is instructed to cancel a response by the sounding of a ‘stop signal’. The time taken to stop the response is termed the Stop Signal Reaction Time (SSRT), which provides a measure of action cancellation. Other outcome measures include mean RTs for correct ‘go’ trials, and total errors on ‘go’ trials. Three studies used the SST to examine differences in action cancellation between groups (Boisseau et al., 2012; Claes, Nederkoorn, Vandereycken, Guerrieri, & Vertommen, 2006; Galimberti, Martoni, Cavallini, Erzegovesi, & Bellodi, 2012). Galimberti et al. (2012) used the SST to look at differences between individuals with AN-Re, AN-Be, BN, and HCs. Overall both AN-Be, and AN-Re groups displayed increased SSRTs compared to HC. There were no differences between groups for mean RTs for correct ‘go’ trials. However, in comparison Claes et al. (2006) found no difference between AN-R, AN-P, BN and HC groups for any of the SST outcome measures. This is in line with more recent findings from Boisseau et al. (2012) who also found no evidence of impaired action cancellation in those with BN compared to HCs.

Interference Control/Verbal Inhibition

Interference control is another form of cognitive control, which is similar to inhibition but requires the suppression of a competing distractor stimulus, whilst simultaneously initiating an alternative response (Nigg, 2000). Measures of interference control used in the included studies of the current review (see Table 2) include the Stroop test, Hayling Sentence Completion Test, and the Simon Spatial Incompatibility Task. These tasks are discussed in turn below.

Stroop Test

The Stroop test (Stroop, 1935) was designed as a measure of executive functioning. Typically participants are given two lists of colour words, and asked to read these aloud. The first list contains words printed in the congruent coloured ink, whereas the second list is printed in an incongruent colour. The accuracy and time taken for the participant to name the printed colour is then recorded. An interference measure is then calculated as the number of correctly named colours for the incongruent list, minus the correctly named colours for the congruent list. Therefore, higher interference scores indicate superior interference/inhibitory control. The original Stroop task has been adapted into an 'Emotional Stroop' in which affective or personally relevant distractors are used instead of the incongruent colour words. Four studies used a version of the Stroop task to measure interference. Kemps and Wilsdon (2010),Van den Eynde et al. (2012), and Fagundo et al (2012) used the original pencil and paper version of the Stroop task to examine differences between individuals with BN and HC. One study showed evidence for impaired interference control for BN compared to HC (Kemps & Wilsdon, 2010), but the other study showed no differences between BN and HC (Van den Eynde et al., 2012). Fagundo et al (2012) found that individuals with AN were significantly impaired when compared to HCs. The final study used a computerised version of the Stroop task, (Camacho Ruiz et al 2008) that included food and body words. Individuals with AN or

BN showed a specific interference effect for negative body shape words; making more errors. In addition individuals with BN took significantly longer for the negative word list compared to HCs.

The Colour-Word Interference test is very similar to the Stroop task and also assesses interference control. Only one study (Brand, Franke-Sievert, Jacoby, Markowitsch, & Tuschen-Caffier, 2007) in the current review used this task, and found no evidence for a differences in performance between BN and HC.

Hayling Sentence Completion Test

The Hayling Sentence Completion Test (HSCT) was developed by Burgess and Shallice (1996), and measures the interference between response initiation and suppression. Participants are read two different sets of incomplete sentences, and asked to respond by providing the last word to complete the sentence. In the first condition (HSCT-initiation) the response given by the participant has to fit the context of the sentence. However, in the second condition (HSCT-suppression) the response has to be irrelevant, although still grammatically correct, (Borella, Carretti, & Pelegrina, 2010). The outcome measure of interference cost is the total number of correct HSCT-suppression completions minus the correct HSCT-initiation completions. A lower score therefore indicates a deficit in interference/inhibitory control. Kemps and Wilsdon (2010), Abbate-Daga et al (2011), and Aloi et al (2015) used the standard version of the HSCT and showed mixed findings. Kemps and Wilsdon, (2010) found that those with BN performed significantly worse than HCs. In a separate study, individuals with AN-R were also found to have a lower score compared to HCs (Abbate-Daga, 2011).

However, Aloi et al (2015) found no differences in performance between AN and HCs. The fourth study to use the HSCT (Pignatti & Bernasconi, 2013) adapted the original version to be used in Italian, with a reduced number of sentences in each condition. Their study showed no evidence of a deficit in interference control for those with AN or BN compared to HCs.

Simon Spatial Incompatibility Task (SSI)

The SSI task measures the interference that results from the side of the screen that the stimulus appears on, and the direction that the stimulus points. During this task stimuli are presented on the screen in the form of arrows, pointing to the left or right, and appearing on either the left or right of a central midline. Therefore, a congruent trial would be when an arrow pointed to the right and the stimulus appeared on the right whereas an incongruent trial would be when an arrow pointed to the right but the stimulus appeared on the left. The main outcome measures are the time taken for the participant to respond, and the accuracy of response (number of errors). An interference measure is then calculated as the mean RTs for incongruent minus congruent trials, and accuracy for incongruent minus congruent trials. The one study to use this measure (Marsh et al., 2009) demonstrated that individuals with BN have smaller RT interference scores than HC but make more interference errors. This indicates a speed accuracy trade off, whereby individuals with BN tend to respond as quickly as possible at the expense of accuracy.

Risk Taking

Almost all real-world behaviour has a certain chance, or risk, of a given outcome, which could be positive or negative (Leigh, 1999; Lejuez et al., 2002). However, for the purpose of the current review, risk taking is defined as the engagement in behaviour to obtain a specific outcome that has an associated probability of being disadvantageous or potentially harmful (Leigh, 1999). The assessment of a construct such as risk taking is difficult, and has previously been measured using self-report instruments, (Barratt, 1985; Eysenck, Pearson, Easting, & Allsopp, 1985; Whiteside, Lynam, Miller, & Reynolds, 2005). However, the degree to which subjective bias and social desirability can influence responses is debated (Ladouceur et al., 2000). Therefore, a more accurate assessment of risk taking should utilise a behavioural measure to reduce potential bias (Lejuez et al., 2002). Measures of risk taking employed in this review include the Bets-16 Task, Game of Dice Task and the Iowa Gambling Task.

Bets-16 Task (Butler & Montgomery, 2005)

During this task participants are given 16 pairs of two outcome hypothetical bets, which are presented in a pie chart format. Each pair of bets has an identical expected value but one choice (guaranteed win) has a large likelihood of a win of a small amount of money vs. a small likelihood of winning a larger amount. In contrast, the other choice (long shot) provides a small chance of winning a large amount or a almost certain chance of winning nothing. Points are awarded for each long shot chosen, which is the more ‘risky choice’. The main outcome variable is this net score, and therefore, a higher overall score indicates more risk taking behaviour. There was only one study to use the Bets-16 Task in individuals with an eating disorder (AN). This study found no evidence of a difference between AN and HC in the number of risky decisions made (Butler & Montgomery, 2005).

Game of Dice Task

The Game of Dice Task (GDT) was designed by Brand et al. (2005) to assess risky decision making in a gambling situation. Participants are given an imaginary starting capital of $1,307 and told to increase this amount through 18 rolls of the dice. At the beginning of each trial, participants are asked to choose a number that will occur in the next throw from a set of fixed options. These options have fixed probabilities of wins and losses, and the associated risk, along with the wins and losses can be easily determined by the participant. In addition, the participants receive immediate feedback based on the choices that they make. Choices are then categorised as either high risk (disadvantageous) or low risk (advantageous). The main outcome variable is calculated by subtracting the disadvantageous from the advantageous choices. Therefore, a lower overall score would indicate a higher proportion of disadvantageous choices; indicating risky decision-making. Two studies (Brand, Franke-Sievert, Jacoby, Markowitsch, & Tuschen-Caffier, 2007; Van den Eynde et al., 2012) examined differences between BN and HC using the GDT. Van den Eynde et al. (2012) showed differences between BN and HC in the number of disadvantageous choices. However, Brand et al. (2007) demonstrated that individuals with BN choose the disadvantageous choice significantly more frequently when compared to HCs and accordingly had a lower net score.

Iowa Gambling Task

The Iowa Gambling Task (IGT) was originally developed to assess real life decision-making in patients with damage to the ventromedial prefrontal cortex. Individuals with damage to this area choose outcomes that yield high immediate gains, despite losses in the future (Bechara, Damasio, Damasio, & Anderson, 1994). The IGT is thought to mimic real life decision making as it combines factors such as uncertainty, reward and punishment and assesses the ability of the individual to discount immediate rewards in favour of future gains (Dunn, Dalgleish, & Lawrence, 2006). The computerised version of the IGT consists of four identical looking decks of cards (A, B, C, & D). Participants are given a hypothetical loan of £2,000 and told to make 100 choices between each of the four decks. The participants are told that, although each selection will result in winning some money, there will also be immediate losses following some choices and the aim is to win as much money as possible. Unknown to the participants, the values of the decks have already been determined. Decks A and B are labelled the disadvantageous decks, which give higher rewards, but also larger losses and are therefore more risky. In contrast, decks C and D are labelled the advantageous decks as they pay out small amounts but rarely give losses and are therefore safer. The 100 choices are then divided into 5 blocks of 20, and a net score for each block is calculated. The net score for each block consists of the total choices from the advantageous decks C and D, subtracted from the disadvantageous A and B decks. In addition, a global net score can be computed as the mean of the choices made across all 100 trials.

Eight studies included in the current review examined IGT performance in individuals with an eating disorder, compared to those without (Brogan, Hevey, & Pignatti, 2010;

Liao et al., 2009; Tchanturia et al., 2012; Adoue et al, 2015; Aloi et al 2015, Danner et al 2012; Fagundo et al, 2012; Abbate-Daga et al, 2011). Liao et al., (2009) showed a significant difference in the net score for all five blocks, and in global net score between both BN and AN compared to HC. Participants in the BN and AN groups showed lower net scores, compared to HCs. Similarly, Brogan et al. (2010) demonstrated lower global net scores in BN vs. HC, and AN vs. HC but no difference between eating disorder groups. Block net scores were significantly lower for blocks 3 and 4 for BN vs. HC and significantly lower for blocks 3, 4, and 5 between AN and HC. In line with this, Tchanturia et al. (2012) reported that a mixed gender sample of individuals with AN performed significantly worse compared to HCs for all blocks except the first. Additionally, Abbate-Daga et al, (2011) showed that individuals with AN-R consistently performed worse when compared to HC for total score and the for the first and last fifty trials; a result also shown by Fagundo et al (2012) who found that AN compared to HC performed worse across all five blocks and for total IGT score. However, Danner et al (2012) only showed significantly lower performance for AN compared to HC for total scores but not for any individual block scores. Further to this Aloi et al (2015) and Adoue et al (2015) showed impaired performance for total IGT scores when comparing AN to HCs but different pattern of results across scores for the individual blocks. Only scores for blocks three, four, and five were significantly different for AN vs. HC in the Adoue et al (2015) study, compared to blocks two and three for the Aloi et al (2015) study.

Balloon Analogue Risk Task (BART)

This computerised task models real-world risky decision making by requiring the participant to balance the potential for reward and loss. Participants are presented with a balloon on the computer screen, and told that they have the opportunity to win money by pressing a button and pumping the balloon up. Each pump of the balloon is incremental and the bigger the balloon is pumped the greater the potential reward, if the participant 'cashes out' before it explodes. The point at which the balloon over inflates and explodes is variable and participants are not told these contingencies. If the balloon bursts without the participant 'cashing in' then the earnings for that trial are lost. Risky decision making is measured as the adjusted average number of pumps on an unexploded balloon (Lejuez et al, 2002).

One study which examined performance on the BART in those with an ED showed that individuals with AN make significantly fewer risky decisions compared to HCs (Adoue et al 2015). Individuals with AN made fewer balloon pumps on unexploded balloons compared to HC;, indicative of lower risky decision making.

Planning

Adequate planning is the ability to successfully organize a sequence of actions, or behaviours in order to take the individual from a current state to a specified goal state (Unterrainer & Owen, 2006). Planning is involved in most everyday activities, and a lack of adequate planning has been suggested to be a part of impulsivity (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Tasks that have been used to measure planning ability include The Tower of London/Hanoi and The Rey-Osterrieth/Complex Figures Task.

The Tower of London

The Tower of London Task (TOL) requires participants to transfer different coloured beads between three rods of varying length, so that larger beads are never put on top of smaller beads, in order to achieve a specified goal arrangement (Shallice, 1982). The difficulty of the task can be manipulated by changing the goal arrangement of the beads or the initial bead placement. The task is hypothesised to involve elements of impulsivity, planning and visuo-spatial working memory. Two studies in the current review used the TOL to assess differences between HCs and eating disorder groups. Brand et al (2007) compared individuals with BN to HCs but found no differences in performance for the TOL task. Camacho Ruiz et al (2008) compared those with BN, AN, and HC. Although there were no differences in the total number of movements, both AN and BN groups took significantly longer to complete the task compared to HCs.

Rey-Osterrieth Complex Figures Task

Originally designed by Rey (1941) and standardised by Osterrieth (1944) the Rey-Osterrieth Complex Figures Task (ROCF) is hypothesised to assess visuospatial ability, nonverbal memory, planning, and strategic organisation (Shin et al, 2006). This task has also been used as a measure of central coherence although these results will not be discussed due to the review not examining central coherence. See Lopez et al, (2015) for a recent review of the literature. During this task participants are asked to copy a complex geometric shape and then reproduce this shape immediately from memory and after a delay. These conditions provide information about memory, planning, and attention. To successfully copy the figure, the participant needs to attend to the figure and integrate visuospatial information about the elements, motor skills to copy, and successful planning of copying order. The delayed and immediate recall conditions additionally rely on non-verbal memory of visuo-spatial arrangements. The outcome measures of accuracy, order completed, and time to complete is used as a marker of an individual's ability. Higher accuracy is taken as an indication of better performance in visuospatial, nonverbal memory, and planning domains. Six studies examined ROCF performance in both eating disorder groups and HCs. Studies varied on the outcome measures reported and scoring methods. Sherman et al (2006), Lopez et al (2008), and Roberts et al (2011) reported order index, which is hypothesised to relate to the planning component on the task.

Roberts et al (2011) examined differences between AN-R, AN-B, BN, and HCs. All ED groups showed significantly lower order index scores when compared to HCs. However, only BN differed from HCs for accuracy and recall scores; performing significantly worse. Similarly Sherman et al (2006) found that AN patients had significantly lower order index scores, compared to HC. AN also performed worse for immediate and delayed recall accuracy, and copy to immediate recall. Lopez et al (2008) found no differences between AN, BN, and HCs for organisational strategy, but individuals with BN had significantly lower copy index and recall accuracy.

Brand et al (2007) only reported delayed recall for the ROCF, showing significantly lower scores for BN compared to HC. However, Danner et al (2012) showed no differences between AN and HC for copy or recall accuracy. Camacho Ruiz et al (2008) compared AN, BN, and HC for total number of recalled elements. Individuals with AN performed significantly worse when compared to BN and HC, and scores for the BN group were also significantly lower when compared to HCs.

1.7.3.2. Compulsivity

Compulsive responding during a behavioural task can be defined as the production of persistent actions that have no obvious relationship to the overall task goal and are often measured using total perseverative errors following a shift of contingencies (Roberts, Tchanturia, Stahl, Southgate, & Treasure, 2007). However, the cognitive mechanisms underpinning these perseverative errors can vary. Some measures of compulsive, or perseverative responding, ask participants to shift attention from one aspect of a stimulus (i.e. shape) towards another aspect (i.e. colour). Compulsive responding after this shift could be related to an inability to shift attention. However, when a task requires participants to shift from performing a response based on one rule (matching based on shape) to a different rule (matching based on colour), the participant needs to override a previously learnt rule, or stimulus-reinforcement association, to prevent perseverative errors. Although an inability with the first type of shift (attentional set-shifting) and the second type of shift (reversal learning) result in the same outcome (compulsive responding) the processes underlying the two behaviours is different. It has therefore been argued that these two processes should be distinguished when investigating cognitive inflexibility in EDs (Wildes, Forbes, & Marcus, 2014).

Therefore studies examining attentional set-shifting will be presented first, followed by those examining reversal learning. Tasks that measure both attentional set-shifting and reversal learning will be presented last.

Attentional Set-Shifting

Trail Making Task (Kravariti et al., 2001, 2003; Toulopoulou et Al., 2003)

The Trail Making Task (TMT) consists of two parts; Part A and B. During Part A participants are asked to draw lines between 25 numbered circles in ascending order. Part B also involves connecting circles but during this part the circles include both numbers (1-13) and numbers (A-L) and participants are required to alternate between the numbers and letters (1-A-2-B, etc.). The outcome measures from this task are the time taken to complete Part A and Part B. A composite score can be calculated by subtracting Part A from Part B. The task can be done using a pencil and paper or via computer programme. Five papers in the current review used the TMT, (Abbate-Daga et al., 2011; Aloi et al., 2015; Brand, Franke-Sievert, Jacoby, Markowitsch, & Tuschen-Caffier, 2007; Holliday, Tchanturia, Landau, Collier, & Treasure, 2014; Roberts, Tchanturia, & Treasure, 2010). Three studies found no differences on the time taken for individuals with AN to complete the TMT when compared to HCs (Abbate-Daga et al., 2011; Holliday et al., 2014; Roberts et al., 2010). Further to this Aloi et al., (2015) found no differences for time to complete parts A and B, or the composite B-A score for those with AN compared to HCs. However, the number of errors made during part B was higher for those with AN. Similarly, Brand et al., (2007) found that there were no differences between individuals with BN and HCs on time taken to complete, but that those with BN made significantly more errors for part B.

Perceptual Set-Shifting

Haptic Illusion Task (Tchanturia et al., 2001; Uznadze, 1966)

This task involves three wooden balls, two smaller balls of 5cm in diameter, and one larger ball measuring 8cm in diameter. The task is designed to measure perceptual shifting ability. Participants are asked to close their eyes and are asked to judge the size of the balls that are placed in each hand. To start, one small and large ball are placed in each hand a total of fifteen times. Then for the next fifteen trials both the small balls are given, and participants are asked whether there is any difference in the size of the balls. Commonly participants report that the hand previously holding the larger ball now contains a smaller ball. This is classified as an illusion, and the number of times this is experienced by the participant is used as a marker of perceptual rigidity. Two studies in the current review used the Haptic Illusion Task and showed a significantly higher number of illusions for AN compared to HCs (Holliday et al., 2014) and for ANR, ANBP, and BN compared to HCs (Roberts et al., 2010).

Reversal Learning

Probabilistic Reversal Learning Task (Dombrovski et al., 2010)

The Probabilistic Reversal Learning Task (PRLT) measures reversal learning during decision making; unaffected by working memory or problem solving ability. During the task participants learn to choose one of two rectangles (red or green) over 80 trials. During the initial 40 trials (acquisition stage), the participant is rewarded for choosing the green rectangle on 80% of the trials, and punished for choosing the red triangle. On 20% of the trials false feedback is provided so that selection of the green rectangle results in punishment and selection of the red rectangle results in reward. In the second

40 trials reversal stage these probabilities are reversed. Participants who correctly respond to eight trials are considered to pass a stage. Perseverative errors capture the tendency to stay, while ignoring punishment feedback, whereas the tendency to switch too often leads to probabilistic switch errors. Adoue et al., (2015) found that the AN group had lower acquisition scores, higher total errors and excessive switching compared to HCs. There were no differences in scores for the reversal stage or perseverative errors. However, after controlling for age and NART scores none of these differences remained significant.

The Brixton Spatial Anticipation Test (Burgess & Shallice, 1997)

This task is designed to measure a participant's ability to detect a rule, follow this rule, and shift behaviour in line with a new rule. Participants are shown ten circles displayed in two horizontal rows of five circles, numbered from one to five. One of these circles is coloured blue on each trial. The placement of the blue circle varies on each trial and is determined by a pre-set rule that is not told to the participant. Participants are asked to indicate the placement of the blue circle on the next trial based on the rule inferred from the previous trial. Responses are coded as correct if they follow the present rule, or if the rule changed and the response followed the new rule. The outcome measure of total errors (out of a possible 55) is used to indicate performance, with higher scores reflecting worse performance. Four studies used the Brixton Spatial Anticipation Test. Two compared performance in those with AN versus HCs, (Adoue et al., 2015; Holliday et al., 2014) and two also included individuals with BN (Roberts et al., 2010; Tchanturia et al., 2011). Results comparing individuals with AN to HCs were mixed. Although Adoue et al., (2015) showed that AN made more errors than HCs, Holliday et al., (2014) found no differences between groups. Studies that also included those with BN generally found that both ANR, ANBP and BN made more errors than HCs (Roberts et al., 2010). However, although Tchanturia et al., (2011) found more errors in AN when compared to BN and HCs, there were no differences between BN and HCs.

The Cat Bat Task (Eliava, 1964; Tchanturia et al., 2002)

The Cat Bat Task has been used as a measure of set shifting. Participants are presented with a short story and are asked to fill in the missing letters as accurately but as quickly as possible. The first part of the story describes contexts in which the participant is prompted to use the letter *'c'* to complete the fragment *'_at'* to become *'cat'*. The second part of the task, known as the shifting part, also requires inserting letters. However *'c'* is no longer appropriate to the context of the story and *'b'* becomes a more logical insertion to make *'bat'*. Participants are therefore required to shift from a previously primed response *('c')* to adapt to the contextual changes and respond with an alternate response *('b')*. Perseverative errors and time taken to complete the task are used as outcome measures. Only one study used the Cat Bat Task and showed that individuals with AN took longer for Bat time (after shift), when compared to HCs, but found no difference for perseverative errors (Holliday et al., 2014).

Tasks measuring attentional set-shifting and reversal learning

Wisconsin Card Sorting Test (Berg, 1948)

The Wisconsin Card Sorting Test (WCST) was designed to measure the ability to shift cognitive strategy in response to changing contingencies. The task has been hypothesised to measure a number of executive functions including attentional set shifting, task/rule switching or reversal, and working memory. Participants are presented with four cards that depict different colours and shapes. The number of shapes and the formation of the shapes also differ. The participant is asked to match a card (presented under the four other cards) but not how to match. However, feedback is given and the participant is told whether the match is correct or not. During the task the matching/sorting rules are randomly varied and the participant must identify the new rule in order to correctly match the cards. Outcome measures from the task include the score/percentage of categories achieved, trials, errors, and perseverative errors. A total of thirteen studies used a version of the WCST to look at differences in performance, seven of which compared AN and HCs (Abbate-Daga et al., 2011; Abbate-Daga, Buzzichelli, Marzola, Amianto, & Fassino, 2014; Aloi et al., 2015; Danner et al., 2012; Fagundo et al., 2012; Nakazato et al., 2009; Talbot, Hay, Buckett, & Touyz, 2015), two of which compared BN and HCs (Brand et al., 2007; Galderisi et al., 2011) with the remaining four studies including both AN and BN compared to HCs (Camacho Ruiz, Escoto Ponce de León, & Mancilla Díaz, 2008; Pignatti & Bernasconi, 2013; Roberts et al., 2010; Tchanturia et al., 2012). In all seven studies comparing AN and HCs, more perseverative errors were found in the AN group (Abbate-Daga et al., 2011; Abbate-Daga et al., 2014; Aloi et al., 2015; Danner et al., 2012; Fagundo et al., 2012; Nakazato et al., 2009; Talbot et al., 2015). However, once correcting for BMI, differences in the Abbate-Daga et al., (2011) study were no longer significant.

The two studies that only included a BN and HC group did not find any differences between groups (Brand et al., 2007; Galderisi et al., 2011). However, the four studies that included a BN group alongside the AN group showed mixed findings. Camacho

Ruiz et al., (2008) and Tchanturia et al., (2012) found that both AN and BN groups made significantly more perseverative errors compared to HCs. Similarly, Roberts et al., (2010) found that ANR, ANBP, and BN had more perseverative errors compared to HC. Pignatti and Bernasconi (2013) found no differences between the BN, AN and HC groups for perseverative errors.

CANTAB ID/ED Set-Shifting Test (Downes et al., 1989)

The Intra/Extra Dimensional (IDED) Task involves attentional set-shifting, visual discrimination and attentional set formation maintenance. The IDED is similar to the WCST with the exception that it is able to dissociate different aspects of cognitive flexibility. During the intra-dimensional shift stage participants' ability to generate rules when novel stimuli are introduced is measured, whereas the extra-dimensional stage assesses the ability to shift attention away from previously relevant stimuli. The stimuli are made up of two dimensions (1) coloured filled shapes and (2) white lines that appear in four rectangles on a computer screen. Simple stimuli are made up of just one of these dimensions, whereas compound stimuli are made up of both dimensions. The participant first starts by viewing two simple stimuli and learns, via feedback, which is the correct one by touching it. After six correct responses, the stimuli and/or rules are changed. These shifts are initially intra-dimensional (colour shapes remain the only relevant dimension), and then extra-dimensional (white lines are the only relevant dimension). Outcome measures include errors, number of trials, and stages completed. The one study to examine set-shifting in eating disorders using this task found no differences between ANR, ANBP, BN and HCs for any of the outcome measures (Galimberti, Martoni, Cavallini, Erzegovesi, & Bellodi, 2012).

1.7.4. Discussion

The aim of this review was to identify and summarise cross sectional research comparing cognitive performance on measures of impulsivity and/or compulsivity between individuals with AN, or BN to HCs. Overall, the results of the review are highly variable, showing mixed results. The reasons for this are explored below.

Brief summary of findings

Impulsivity

Studies examining impulsivity across individuals with AN, or BN compared to HCs demonstrated mixed findings. There were no studies that examined action inhibition in those with AN. However, evidence for decreased action inhibition in BN, compared to HCs, was observed in a study that used disorder specific stimuli (food words). Three studies examining action cancellation included individuals with AN; one found evidence for and two found evidence against a deficit.

Similarly, the evidence for impairments in interference control was mixed. Studies in this category used different methods of assessment that could have contributed to the mixed findings. Four studies found no differences between BN and HCs across the different tasks used. However, three studies did find that individuals with BN had greater interference compared to HCs. Three studies looked at AN versus HCs and showed impairments in interference control in the AN group. Method of assessment (pen and paper vs. computer) varied across studies, as did stimuli used (disorder relevant vs. neutral).

Findings for risky decision-making were also mixed when comparisons were made across different tasks. Although two paradigms (Bets-16 & BART) showed no evidence for increased risky decision-making in those with AN, compared to HCs, the findings were opposite for the IGT. Of the eight studies that compared AN to HCs on the IGT, all showed some impairment for AN. Two studies examining risky decision-making on the IGT in BN found impairments when compared to HCs.

The construct of planning was assessed in both AN, and BN groups. Two paradigms were used to measure this construct; the TOL and the ROCFT. Two studies looked at differences between BN, AN, and HCs using the TOL, but found no clear differences in planning between groups. However, studies using the ROCFT found a more consistent pattern. Four studies that included individuals with BN found lower planning. Three out of the five studies to include AN found lower performance compared to HCs. However, the outcome measures used differed across studies, and consequently limits firm comparisons.

Compulsivity

Evidence for increased compulsivity across AN and BN groups was reviewed in the domains of attentional set-shifting, perceptual set-shifting, and reversal learning. The majority of studies examining attentional set-shifting were conducted in AN (N= 4). Although all four studies showed no differences in time to complete the task, one study showed more errors for AN compared to HC. Similarly, the one study to examine BN showed no differences in completion times, but more errors, when compared to HCs. Evidence of an impairment in perceptual set-shifting was present for both AN and BN.

Studies examining reversal learning were largely carried out in AN. The tasks used to examine this construct were heterogeneous. One study (PRL task) found no differences between AN and HCs. Yet, studies that used the Brixton task found more consistent results. Three of these four studies found more errors for AN compared to HC, whilst one study found no differences. The two studies examining BN compared to HCs found opposing results. One study found higher errors, whereas the other failed to find any differences. There was only one study that used the Cat Bat task, and no differences in perseverative errors between AN and HCs were found. However, individuals with AN did take significantly longer to complete the task.

A total of thirteen studies used varying versions of the WCST to examine perseverative responding. All seven studies that compared AN to HCs showed increased perseverative errors for the AN group. The two studies examining differences between BN and HCs found no evidence of increased perseverative responding. Of the studies that included both AN and BN, three studies found group differences, whilst one study found no difference.

The review has shown mixed findings for the cognitive performance of individuals with AN or BN, when compared to HCs on measures assessing aspects of impulsivity/compulsivity. There does not appear to be a clear differentiation between AN and BN in regard to increased/decreased impulsivity or compulsivity; which is consistent with a trans-diagnostic view. There is some evidence to suggest increased impulsivity in AN (interference/risky decision making), although the extent to which performance on these tasks reflects ‘pure’ impulsivity is debated. Findings from the IGT indicated higher risky decision making in those with AN compared to HCs. However, task performance could be related to a number of factors including sensitivity to reward and punishment, known to be affected in individuals with AN (Jappe, Leah, et al., 2011). Additionally, the WCST measures interference but the task involves other executive functions, such as set-shifting, (Van den Eynde, 2014). The ability to shift set has previously been shown to be disrupted in AN, and this view is supported by evidence in the current review. The conceptualisation of AN as having trait impairments in set-shifting and compulsive responding seems to be supported. However, problems with the tasks assessing multiple constructs limits the conclusions that can be drawn regarding AN and impulsivity.

This review did not find strong evidence in favour of increased impulsivity in BN, when compared to HCs, across different measurements. There appeared to be a mixed picture, with some studies showing increased impulsivity, and others no effect. Studies showing increased impulsivity tended to incorporate disorder relevant stimuli (food words). Generally, the evidence does not seem to support the simplistic view of AN as a disorder of compulsivity, and BN as having problems of impulse control. Together the results point to a more balanced view of co-occurring impulsive and compulsive behaviour. This provides support to the view of impulsivity and compulsivity occurring trans-diagnostically.

1.7.4.1. Limitations

Comparisons between AN, BN, and HCs on measures of impulsivity or compulsivity are limited due to the heterogeneous tasks used to measure the same constructs. Additionally, studies utilising the same task, such as the ROCFT, reported different outcome measures, (order index vs. delayed recall). This prevents comparisons between studies, and precludes any firm conclusions from being drawn. Additionally, the terminology used to refer to different constructs of impulsivity and/or compulsivity is not consistent and makes synthesis of results difficult. Some of the measures included in the current review, such as the IGT and WCST, have been criticised for involving and assessing multiple processes. This makes the interpretation of results more complex, and impairments on these tasks could be related to one or more of these processes. Furthermore, the distribution of studies looking at impulsive traits tended to include BN, whereas the examination of compulsive traits tended to examine AN.

A further limitation of the synthesis of the evidence in this way is the assumption that the studies included similar ED groups, and that tasks were administered in a similar manner across studies. Differences in task administration (pen and paper vs. computer) may have biased results, particularly for outcome measures involving reaction times. It is likely that there may be differences in the included patient groups that could confound the results. Patients may have differed according to current medication, general intelligence, co-morbidities, and state of starvation. Although BN and HCs are often matched for BMI, this is not the case for AN. Individuals with AN, by definition, are at a significantly lower body weight; often accompanied by symptoms of starvation. In addition, it is likely that some individuals with AN were tested whilst undergoing refeeding in inpatient units, which could have affected the degree of acute starvation. Studies rarely reported sufficient information about recruitment to determine the degree to which this could have affected findings. Similarly, although individuals with BN were generally matched to HCs for BMI, such individuals routinely fast and no measure of this was taken. McConnellogue, Bamford, Gilbert, and Serpell (under consideration) found that 60% of individuals with BN reported (on the EDE-Q6) having fasted for a minimum of eight hours on at least 1 of the last 28 days. Moreover, 33% of BN participants reported having fasted for a minimum of eight hours on at least 13 of the last 28 days. This indicates that short-term fasting is common in individuals with BN, and is not reflected by a low BMI.

Another issue that limits comparisons between the different patient groups and healthy controls are comorbidities associated with the disorder. Outcome measures need to be considered in relation to co-morbidities such as anxiety, depression and (in AN) low body weight. Anxiety and depression have both been shown to affect cognitive function, (Austin, Mitchell, & Goodwin, 2001). A further confounding factor is the difference between groups in terms of BMI and state of starvation. Employing statistical approaches to account for these confounding factors is problematic. For example, a study is conducted comparing the heights of 5-year-olds and 7-year-olds. The significant difference is the ‘corrected’ to account for age. The significant difference then goes away, but concluding that the 5-year-olds are just as tall as 7-year-olds is then biased. Therefore, the influence of the co-morbidities on the tasks needs to be studied in isolation. This would establish whether starvation, for example, influences task performance. Furthermore, a measure of historic eating disorder diagnosis should be taken. Participants in the BN group may have previously had AN, and this may bias results.

A limitation of this review was the exclusion of studies that did not categorise individuals into groups based on diagnostic criteria. This means that studies categorising individuals according to symptoms, such as AN restrictive subtype or AN bingeing-purging subtype were not included (Claes, Vandereycken, & Vertommen, 2002). Although this approach was recommended during the introduction to this chapter, comparing results according to symptoms to existing data based on diagnostic groups is difficult due to differences in the included patients. However, the exclusion of these studies could have biased the results of the review. Future research should reach a consensus and take a consistent approach to defining the different patient groups for inclusion into research studies.

Future considerations

This systematic evaluation of the existing literature highlights important areas of improvement and investigation for future research studies. Future studies should conduct power calculations to estimate the required sample size in order to be able to detect differences between groups, if present. Main outcome measures should be defined a priori, with reporting of effect sizes. Tasks that isolate the separate components of impulsivity and compulsivity should be prioritised but this could lead to problems comparing current evidence to previous literature. However, it is clear that a more strategic approach to methodology and reporting would benefit the field. A consensus needs to be reached on the appropriate paradigms to measure different constructs so that the same outcome measures from different studies can be compared, preferentially in a meta-analysis.

1.7.4.2. Thesis Rationale

Starvation is rarely addressed in eating disorders research but is a clinical feature of AN. Starvation is defined as a severe deficit in the required calorie intake to sustain homeostasis, and is a dangerous form of malnutrition. Prolonged starvation leads to organ failure, and eventually death. The Body Mass Index (BMI) of an individual with AN is usually categorised as underweight, indicative of chronic starvation, coupled with short-term food restriction (Sidiropoulos, 2007; Vitousek & Manke, 1994). Whilst the BMI of individuals with BN remains within a normal range, individuals with BN engage in episodes of fasting or minimal calorie intake, and hence are likely to undergo periods of acute rather than chronic starvation. Fasting, in this context, is the voluntary abstinence from food for variable amounts of time. The role of starvation as a causal factor or consequence of having an eating disorder has been debated but remains difficult to research (Treasure, 2007). Manipulating chronic starvation to examine effects on behaviour would be considered unethical by today's standards. However, existing research on members of the general (non-eating disordered population) in which fasting is manipulated has given some insight into the influence of acute starvation on behaviour (Pender, Gilbert, & Serpell, 2014; Bolton, Burgess, Gilbert, & Serpell, 2014).

The Minnesota Starvation Experiment by Keys (1950) was initially designed to understand more about the malnutrition experienced by concentration camp inmates in the Second World War, and to research different methods of re-feeding which could be used for such individuals. A group of male conscientious objectors voluntarily took part and were subjected to a reduced calorie intake, and an increased exercise regime over a three month period to reduce to 74% of their initial weight. Interestingly, Keys (1950) reported several behaviours during the starvation period similar to those observed in AN and BN. The men were preoccupied with food, hoarded food items, and developed ritualistic eating behaviours. Once re-fed to their initial weight some of the men continued eating despite being full, and engaged in periods of bingeing and dieting (Keys, 1950). Following on from this work Polivy and colleagues (1994) followed up a group of Second World War prisoners who had lost up to 15% of their body weight due to food restriction whilst in captivity. In comparison to a group of combat veterans the group of prisoners of war had significantly higher levels of binge eating after being liberated.

In line with the results from Keyes (1950) research has shown that in some cases unintentional weight loss can lead to the onset of AN (Brandenburg & Andersen, 2007; Epling, Pierce & Stefan, 1981) which could suggest a causal role for starvation. However, research has also looked at the possible consequences of starvation showing decreases in grey matter volume and density in the brain for individuals with AN compared to HCs (Suchan, Busch, Schulte, Grönermeyer, Herpertz, & Vocks, 2010; Mühlau, Gaser, Ilg, Conrad, Leibl, et al. 2007). Therefore, the extent to which starvation may be a cause of AN or explain some of the features of AN is unclear. However, what is clear is that a more complete understanding and investigation of the cognitive effects of starvation is warranted, even if this needs to be conducted with healthy controls. The enduring impact of the work of Keys (1950) demonstrates the usefulness of studying starvation and calorie deprivation in the general population, without the confounding effects of the eating disorder. This would then allow for the generation of hypotheses about the role of starvation in eating disorders. Another way in which the impact of starvation on neurocognition could be studied is by including participants who are low in weight due to physical illness or treatment, such as those undergoing chemotherapy for cancer or those with gastrointestinal disorders associated with malabsorption. However, the process of matching these individuals to those with AN is complex, due, for example to the fact that chemotherapy can have neurotoxic effects which could impair performance on behavioural tasks.

Recent research has demonstrated that fasting for 18-24 hours can affect executive functioning, such as increasing difficulty in set shifting and increasing the focus on detail at the expense of the bigger picture (Pender et al., 2014). It is possible that some of the inconsistent findings identified by the current review could be accounted for by differences in the short-term fasting or starvation present in eating disorder groups. Additionally, if some of the measures of impulsivity and/or compulsivity can be influenced by the state (fasted vs. satiated) of the individual, this would question whether the traits of impulsivity and compulsivity reflect true endophenotypes.

Research questions

The aim of this thesis is to examine the role of short-term fasting on cognitive performance. Specifically, this thesis aims to answer the following questions:

1. Can short-term fasting influence performance on cognitive measures of impulsivity?

2. Can short-term fasting influence performance on cognitive measures of compulsivity?

3. If so, to what degree can self-reported hunger account for any impairment in cognitive performance on these measures of impulsivity and compulsivity?

4. What possible mechanisms could account for any effects of fasting? In particular, is any observed effect of fasting related to cravings induced through food deprivation?

2. Chapter Two

Does short-term fasting influence impulsivity in a non-clinical population?

The role of personality traits in the emergence of eating disorder psychopathology has been extensively investigated using both self-report and behavioural measures (Vitousek & Manke, 1994). Traditionally, individuals with bulimia nervosa (BN) have been labelled as impulsive, whereas individuals with anorexia nervosa (AN) have been regarded as compulsive in their behaviour (Waxman, 2009; Godier & Park, 2014). The systematic review of research in this area (Chapter 1) examined the evidence for increased impulsivity in BN (as well as increased compulsivity in AN). However, the systematic review showed inconsistent support for these views. This could be due to a number of factors. The studies included in the systematic review used different measures to examine the same construct. The construct of impulsivity is multifaceted and a particular measure may only be assessing one of these components, or multiple components (Daruna, 1993). For example, the GoNo Go Task is used to measure action inhibition, whereas the Iowa Gambling Task combines elements of risky decision-making but also involves elements of learning (Upton, Bishara, Ahn, & Stout, 2011). This makes comparisons between different measures difficult and limits generalisability (Dunn, 2006).

Alternatively, or additionally, the inconsistent findings of the systematic review could be due to some of the symptoms of the eating disorder affecting task performance. For example, research has demonstrated detrimental effects of fasting on mood, behaviour, and cognition (Benau, Orloff, Janke, Serpell, & Timko, 2014). Although HC and BN groups are matched according to Body Mass Index (BMI) a marker of chronic starvation, short-term eating behaviours are not routinely measured. Individuals with BN may engage in acute starvation (short-term fasting) in order to compensate for over-eating (Vitousek & Manke, 1994). This is an important methodological consideration as the behavioural expression of impulsivity has been shown to be influenced by fasting (Symmonds, et al., 2010; Levy, Thavikulwat, & Glimcher 2013). Symmonds and colleagues (2015) have investigated whether human risk preferences vary as a function of metabolic state. Participants were asked to choose between different lottery options each associated with different 'risk'. The same task was administered after fasting for an hour, following satiation with a meal, and one hour after the meal. Results showed that participants risk preference varied according to levels of hunger and satiation; participants were more risk seeking when hungry and more risk-averse when satiated.

Levy and colleagues (2013) have also demonstrated that risk attitudes vary according to the internal state of an individual. On average, participants choices towards both monetary and consumable rewards were more risk-tolerant when fasted, compared to when satiated. This indicates that the state of an individual can have a significant influence on risky decision-making, such that fasted individuals appear more willing to take risks. This variability could be understood to have evolutionary value, given that higher risk taking is needed to prevent starvation in conditions of scarce food availability (Symmonds, Emmanuel, Drew, Batterham, & Dolan, 2010). However, it is unclear whether other components of impulsivity would be influenced by fasting manipulations in a similar direction. This underexplored area could have important implications, especially in the field of eating disorders, in which both fasting and increased impulsivity are involved. Understanding the role of short term fasting in decision-making may help disentangle the effect of eating disorder psychopathology on cognition from the effect of long-term calorie deprivation.

Therefore an investigation into the influence of fasting on impulsivity is clearly needed. One paradigm which is increasingly used in the field is to measure task performance in HCs for fasted and satiated states in a within-subject design (e.g. Bolton, Burgess, Gilbert, & Serpell, 2014; Pender, Gilbert, & Serpell, 2014). Given the complex, multidimensional nature of impulsivity, and the differing findings shown by the systematic review, different components of impulsivity need to be examined within the same experimental design, in order to tease out the contribution of each component. Therefore, the current study aims to examine the effect of short-term fasting on performance on well designed and validated tasks measuring four important components of impulsivity in HCs.

The four components of impulsivity (reflection impulsivity, action inhibition, risky decision making, and delay aversion) described by Evenden (1999) and identified during the systematic review (Chapter 1) will be investigated. Reflection impulsivity refers to an inability to collect and reflect on information before making a decision, and can be measured using the Matching Familiar Figures Test (Kagan et al., 1964). Participants are asked to decide whether figures presented on a screen match one another. The combination of faster and inaccurate responses is associated with higher reflection impulsivity.

Action inhibition has been described as the failure to inhibit a motor response, and is commonly measured using the Go/NoGo task (Murphy et al., 1999). Participants are told to respond to target stimuli (Go), and to inhibit responses to distractor stimuli (NoGo). A greater number of incorrect responses to the distractor stimuli (commission error) is hypothesised to indicate action inhibition difficulties.

Risky decision-making is the tendency to select a larger but less likely versus a smaller but more likely reward and has been measured in a number of different ways, including the Game of Dice Task (Brand et al., 2005). Participants are given a hypothetical amount of money and instructed to increase this capital by guessing the number that will be rolled on a subsequent dice roll. Participants are given a set of fixed options that differ for probability of wins, losses, and associated risk. Individuals who make more high risk choices are characterised as impulsive.

Delay aversion has been defined as a preference for smaller rewards sooner vs. larger rewards later (Evenden, 1999). The concept of impulsive choice has been captured by tasks such as the Temporal Discounting Task that measures the degree to which an individual is driven by immediate gratification vs. the prospect of a delayed reward (Pine et al., 2009).

In line with the findings that human risk attitudes vary as a function of metabolic state (Symmonds, et al., 2010; Levy, Thavikulwat, & Glimcher 2013), the primary hypothesis was that:

1. Short-term fasting would increase risky (i.e. low probability) choices during decision-making. Additionally, the effect of short-term fasting on measures of action inhibition, reflection impulsivity, and delay aversion were explored.

It was hypothesised that:

2. Short-term fasting would be associated with an increase in commission errors on a task of action inhibition;
3. Short-term fasting would decrease the amount of information sampled before making a decision on a task of reflection impulsivity; and
4. Short-term fasting would decrease the amount of time individuals are willing to wait to receive a reward during a delay aversion task.

2.1. Methods

Participants

Power calculation for a repeated measures, within subject ANOVA with a small effect size (0.25) and 90% power conducted in G*Power indicated a required sample size of 30. Thirty-three female participants (mean age = 25 years; *SD* = 8.26; range = 18.5-56) were recruited through the University College London (UCL) subject pool. Eligible participants were female, aged 18-50, and had a BMI >18.5. Participants were excluded if: they were currently being treated for any serious medical or psychological condition including diabetes, they had any history of neurological illness or head injury, previous eating disorder, or were currently pregnant or breastfeeding. Participants either received course credits or were reimbursed for their time. This study was approved by the university research ethics committee. Participants gave written informed consent and a full debrief was provided at the end of the study.

Procedure

The study used a within-subjects repeated-measures design, assessing behaviour under two conditions: once when participants had fasted for 20 hours and once when satiated. The mean time between sessions was 7.2 days (*SD* = 1.7, range = 6-16), with each session lasting 90 minutes. During the first session participants underwent the Mini International Neuropsychiatric Interview (MINI), used to assess DSM-IV Axis 1 disorders (Lecrubier, Sheehan, Weiller, Amorim, Bonora, Harnett Sheehan, Janavs, & Dunbar, 1997) and completed four behavioural tasks. During the other session participants completed questionnaires and the same behavioural tasks. Task and session order (fasted/satiated) were counterbalanced and randomised. Fasting adherence was assessed using self-reported hunger and blood glucose readings from the distal phalanx area of the index finger using the Freestyle Freedom Lite Blood Glucose Monitoring System, supplied by Abbott Diabetes Care, UK (www.abbottdiabetescare.co.uk). All behavioural tasks were administered on a laptop computer, positioned approximately 60cm from the participant.

Measures

Questionnaires

Participants completed: the Beck Depression Inventory (BDI–II, Beck, Steer, Ball, & Ranieri, 1996) a measure of the severity of depressive symptoms; the Eating Disorder Examination Questionnaire-6 (EDEQ-6; Fairburn & Beglin, 1994), to measure ED symptoms; the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), to measure anxiety; and The Impulsive Behaviour Scale (UPPS; Whiteside & Lynam, 2001), to assess impulsivity. Additionally, participants filled in a hunger questionnaire that consisted of four Likert scales measuring hunger, desire to eat, the amount of food the participant could eat, and fullness. Participants were also asked to rate from *not at all* to *very much so* how much they were experiencing each of the following: dry mouth, stomach aches, anxiety, dizziness, weakness, nausea, thirst, headache, and stomach growling. A composite score was calculated by adding together the four Likert ratings associated with the subjective hunger and the nine ratings of physical side effects. A higher score indicated higher levels of self-reported hunger.

2.1.1. Experimental Tasks

Information Sampling Task (Clark, Robbins, Ersche, & Sahakian, 2006) to measure reflection impulsivity, see Fig 3.

The Information Sampling Task (IST) measures the degree to which participants sample information before making a decision, whilst placing minimal demands on visual processing and working memory. Participants are shown a 5x5 matrix of 25 grey boxes and are told that each grey box covers one of two possible colours. Participants must decide which colour they think is in the majority, and can click to uncover as many boxes as they wish before deciding. Once opened, boxes remain visible for the remainder of that trial. Correct decisions in the Fixed Win (FW) condition are awarded 100 points irrespective of number of boxes opened. In the Decreasing Win (DW) condition the number of points to be won decreases by 10 points with every box opened. Therefore in the DW condition participants must tolerate higher uncertainty to win a high number of points as sampling information to a point of high certainty would win few points.

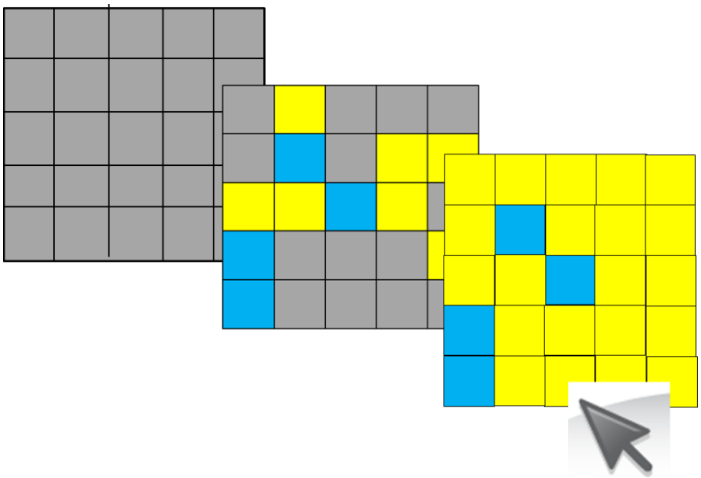


Figure 3. Pictorial representation of the box opening made during the IST.

Accuracy scores for identifying the correct box colour were examined and any participants with accuracy scores lower than 60% were excluded from further analysis, in line with the original study (Clark, et al, 2006).

To investigate the effect of fasting on the amount of information sampled during the IST, the dependent variable, the average number of boxes opened before making a decision was entered into a multivariate analysis.

Temporal Discounting Task (TDT, Pine, Seymour, Roiser, Bossaert, Friston, Curran, & Dolan, 2009) to measure delay aversion, see Fig 4.

Temporal discounting is the degree to which individuals discount forthcoming rewards. For instance comparing smaller gains in the nearer future to larger gains in the farther future. The latter are treated as being less valuable than their nominal worth, typically following a hyperbolic form with a discount rate parameter *k*.

Figure 4. Example screenshot from the Temporal Discounting Task.

Participants were asked, on 220 trials to choose between a pair of serially presented options of differing magnitude, ranging from a monetary value of £1 to £100, and a time delay of one week to one year. For example, participants were asked to choose between receiving £15 in 2 weeks or £57 in 7 months. As in the original study (Pine et al., 2009), participants were told that one of the options they chose would be randomly selected and paid for on a pre-paid card with a timed activation date. The task also contained 20 trials in which one of the choices presented was always both larger and available sooner. These 'catch' trials were used to determine the subject was paying attention to, and understood the task, but not to assess the degree of discounting. Participants who scored under 80% on the catch trials across both sessions were excluded from further analysis. The remaining participants scored a mean of 19.15 out of a possible 20 on the catch trials.

Impulsive choice was calculated as the number of sooner options chosen by each participant for each trial, separately for the fasted and satiated sessions. A pairwise comparison was used to examine any differences across fasted and satiated sessions.

We fitted subjects' choices to a model which included three parameters: the discount rate (k), utility concavity (r) and inverse temperature (β) associated with a softmax choice. See Pine and colleagues (2009) for full details. The values of the parameters that maximised the probability of the choices of each subject, on each session, were determined using optimisation functions in Matlab (The MathWorks Inc., Natick, MA, United States). Pairwise comparisons were run to examine any differences in the discount rate (k), or utility concavity (r), between fasted and satiated sessions.

Impulsive choice was calculated as the number of sooner options chosen by each participant for each trial, separately for the fasted and satiated sessions. A pairwise comparison was used to examine any differences across fasted and satiated sessions.

Choice x Risk Task (CRT, Rogers, Tunbridge, Bhagwagar, Drevets, Sahakian, & Carter, 2003) to measure risky decision making, see Fig 5.

The Choice x Risk task is used to investigate three factors thought to affect decision-making: the magnitude of expected gains (reward), the magnitude of expected losses (punishment) and the probabilities of each. On each trial participants were required to choose between two gambles, represented as two bars simultaneously presented on the screen. The amount the bar is filled represents the probability of winning, while wins and losses are displayed numerically at the top and bottom of each bar in green and red text respectively. Participants complete four games, consisting of 20 trials presented in a pseudorandom order. There are eight repetitions of each of 10 trial types, including "gain only" and "loss only" trials. Participants were given 100 points at the beginning of each game and instructed to win as many points as possible. After each trial feedback was given on performance and an updated score was displayed for two seconds.

Standard trial types always contained a control gamble (50/50 chance of winning 10 points) and an experimental gamble. The experimental gamble varied in the probability of winning to be either high or low (75 vs. 25), expected gains to be either large or small (80 vs. 20 points) and expected losses to be either large or small (80 vs. 20 points) producing eight trial types.

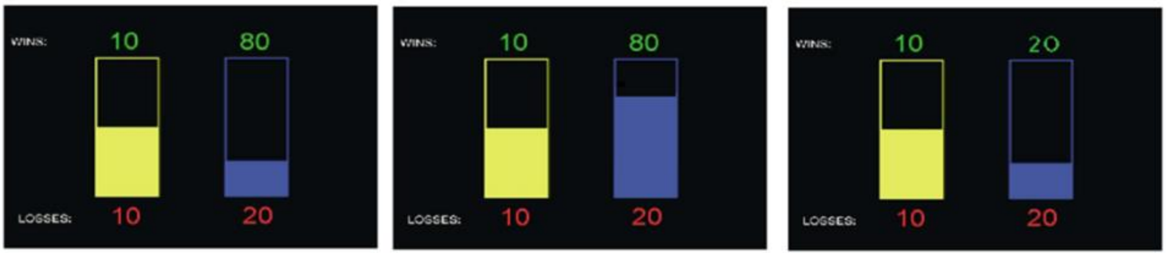


Figure 5. Example trial types from the Choice x Risk Task

The other two trial types, 'gain only' and 'loss only' were used to estimate (what is typically found to be) risk-aversion when choosing between gains, and (typically) risk-seeking when choosing between losses. In a 'gains only' trial, two options with the same expected value are presented. For example, participants are more likely to choose a 100% chance of a gain of £20, compared to a 50% chance of gaining £40 indicating risk-aversion for gains. In a 'loss only' trial two options presented, such as a 50% chance of a £40 loss, compared to a 100% chance of a £20 loss. Despite both these options having the same expected value, most participants are more likely to choose the 50% of a £40 loss indicating risk-seeking for losses.

Multivariate analysis was conducted on the number of times participants choose the experimental over the control gamble (proportionate choice) and the mean deliberation times associated with these choices. The proportionate choices were arcsine transformed prior to statistical analysis, in line with Rogers, (2003). However, all values presented in tables are untransformed scores for ease of interpretation.

Affective Shifting Task (AST, modified from Murphy, Sahakian, Rubinsztein, Michael, Rogers, Robbins, & Paykel, 1999) to measure action inhibition, see Fig 6.

The AST is a measure of motor inhibitory control. Participants are asked to respond to target stimuli by depressing the space bar (go), and to inhibit responses to distractor stimuli (not depressing the space bar - no-go) as quickly as possible, while maintaining high accuracy. Stimuli were pictures of food (F) or household items (H) presented rapidly, one at a time in the centre of the screen. Photographic stimuli of food and household items were taken from an existing database designed for neuropsychological studies of AN (Uher et al., 2006). Instructions at the beginning of each block indicated to which stimulus type to respond. Each stimulus was presented for 300ms with an inter-trial interval of 900ms. There were 10 blocks (2 practice blocks) with 18 stimuli presented in each block, arranged in either of the following orders: FFHHFFHHFF, HHFFHHFFHH. This order means that four blocks become ‘shift’ blocks, in which participants must respond to stimuli that were previously distractors, and inhibit responding to previous targets. In the ‘non-shift’ blocks participants must continue responding to the same targets and inhibiting responses to the same distractors as in the immediately previous block.

The time taken (RTs) to respond to targets, failures to respond (omissions), and incorrect responses (commission errors) are recorded, with the latter providing a measure of motor inhibition. A 500ms/450 Hz tone sounded for each commission error but not for omissions.

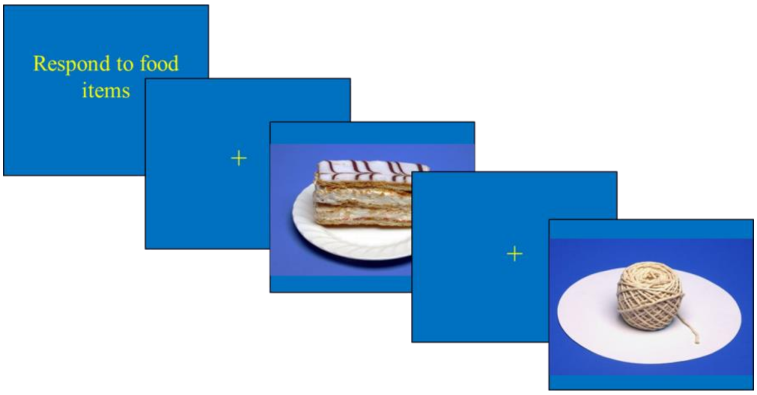


Figure 6. Example trial sequence during the Affective Shifting Task

2.1.2. Statistical Analysis

All statistical analyses were performed using SPSS 21 (IBM SPSS, 2010, Chicago, IL, USA). Two-tailed statistical significance was determined as $p < 0.05$. Descriptive statistics (mean and standard deviations) were calculated for all demographic and questionnaire scores.

Information Sampling Task

A mixed model ANOVA with the within-subject factors of Session (fasted, satiated), Condition (Fixed Win, Decreasing Win) and the between-subject factor of Order (FW-DW, DW-FW) was conducted separately on the primary outcome of average boxes opened, and the secondary outcome of errors. Any significant interactions were then explored with Bonferroni corrections applied to reduce the risk of type 1 error.

Temporal Discounting Task

Maximum likelihood estimation was used in order to calculate the maximum likelihood parameters for the discount rate (*k*), and utility concavity (*r*). For each participant the probability was calculated for each option that was chosen from the 220 choices using the softmax function, and implemented with optimization functions in Matlab (The MathWorks Inc., Natick, MA, United States). See Pine and colleagues' (2009) for further information and methods. Pairwise comparisons were run to examine any differences in the discount rate (*k*), or utility concavity (*r*), between fasted and satiated sessions.

Choice x Risk Task

The proportionate choices were analysed using a within subjects repeated measures 2 x 2 x 2 x 2 ANOVA with the factors of session (fast vs. satiated), probability (high vs. low), expected gains (large vs. small), and expected losses (large vs. small). This ANOVA was then repeated with mean deliberation times (ms) as the dependent variable.

The 'gains only' and 'losses only' trials were analysed separately using a within subjects repeated measures 2 x 2 ANOVA with session (fast vs. satiated), and trial type ('gains only' vs. 'losses only'). Analysis was conducted on both proportion and deliberation times separately.

Affective Shifting Task

Multivariate analyses were conducted separately on reaction times (ms), errors of commission, and errors of omission using a 2 x 2 x 2 repeated measures ANOVA with

Stimuli (food, household), Condition (shift, non-shift), and Session (fast, satiated) entered as within-subject factors. Any significant interactions were then explored, with appropriate Bonferroni corrections being applied.

2.2. Results

Demographic characteristics and questionnaire scores are displayed in Table 3.

Physiological Analysis

Blood Glucose

Pairwise comparisons revealed a significant difference for blood glucose levels between fasting and satiated sessions $t(33)= -5.07$, $p<0.001$. Blood glucose levels in the fasted session (M=4.06, SD=0.51) were lower than in the satiated session (M=4.90, SD=.871).

Correlations between Self-Reported Hunger and Blood Glucose Levels

There were no significant correlations between blood glucose and self-reported hunger on the fasted session ($r(33)=-0.335$, $p=0.065$), or satiated session ($r(33)=-0.351$, $p=0.053$).

Table 3. Means and standard deviations for demographic variables and trait measures.

	Mean ± SD
Demographic Variables	
Age (years)	25.42 ± 8.26
Body Mass Index (BMI)	21.65 ± 3.22
Trait Measures	
UPPS-P	85.18 ± 11.55
BDI	5.15 ± 4.87
EDE-Q	7.97 ± 6.45
Trait-STAI	39.30 ± 9.96

UPPS-P = the Impulsive Behaviour Scale; BDI = Beck Depression Inventory; EDE-Q = Eating Disorder Examination Questionnaire-6; STAI = State-Trait Anxiety Inventory

Information Sampling Task

Data from two participants was excluded from further analysis due to accuracy scores below 60%.

Number of Boxes Opened

For the dependent variable of number of boxes opened, there was a significant main effect of Session [F(1,31)=9.72, p=0.004], a significant main effect of Condition [F(1,31)=76.16, p<0.001] and a significant Session x Condition interaction [F(1,31)=4.49, p<0.05]. There was no significant effect of Condition Order for the fasting [F(1,31)=0.008, p=0.928] or satiated Session [F(1,31)=0.284, p=0.599]. Pairwise comparisons revealed that participants opened significantly fewer boxes in the DW condition, compared to FW for both fasting t(31)=7.86, p<0.001 and satiated t(31=6.78, p<0.001) sessions. See Table 4 for mean scores.

Post-hoc analysis revealed a significant difference between sessions in the FW condition t(31)=3.81, p=0.001 but not the DW condition t(31)=1.41, p=0.168. During the FW condition participants opened more boxes before making a decision when fasted (*M*= 17.07, *SD*=4.45) compared to when satiated (*M*=13.73, *SD*=5.05).

Table 4. Mean difference and standard deviation (±) scores across fasted and satiated sessions

Measure	Fasted		Satiated	
	DW Condition	FW Condition	DW Condition	FW Condition
Boxes Opened	10.41 ± 4.08	17.07 ± 4.45	9.79 ± 3.72	13.73 ± 5.05
Errors	1.90 ± 1.33	0.71 ± 0.90	2.10± 1.42	1.29 ± 1.22

Errors

Analysis of error data using a mixed model ANOVA showed a significant main effect of Session [$F(1,31)=5.75$, $p<0.05$], and a significant main effect of Condition[$F(1,31)=22.21$, $p<0.001$]. The Session x Condition interaction was not significant [$F(1,31)=0.744$, $p=0.396$]. Participants made more errors during the satiated session, and more errors during the DW condition. See Table 4 for mean scores and standard deviations.

Temporal Discounting Task

Two participants scored under 80% on the catch trials across both sessions and were excluded from further analysis. Participants varied on the number of trials in which the sooner option was chosen, ranging from 2 to 184, out of a possible 200 trials. The best fit model from Pine et al., (2009) showed that participants discounted the value of future rewards (mean fasted $k = 0.06$, SD = 0.68; mean satiated $k = 0.07$, SD = 0.066) and demonstrated a concave utility function (mean fasted $r = 0.0213$, SD = 0.03609; mean satiated $r = 0.0140$, SD = 0.02830). However, the discount rate $t(31)= -0.521$, $p=0.606$ and concavity $t(31)= 1.438$, $p=0.161$ were not significantly different between fasted and satiated sessions. The impulsive choices made did not differ across session either $t(31)= -0.327$, $p=0.746$.

Choice x Risk Task

Probability, Wins, and Losses

Data from three participants was not collected for the Choice x Risk Task and therefore 30 participants were included in the following analyses.

Proportionate Choice

There was no main effect of Session (fasted, satiated) on the proportion of times that participants chose the 'experimental' gamble over the 'control' gamble [$F(1,30)=0.22$, $p=0.643$]. However, participants chose the 'experimental' gamble significantly more often when the probability of winning was high compared to when it was low [$F(1,30)=204.73$, $p<0.001$], significantly less often when the expected losses were large compared to small [$F(1,30)=32.95$, $p<0.001$], and significantly more often when the expected gains were large compared to when they were small [$F(1,30)=28.30$, $p<0.001$]. However, there was no significant interaction that involved Session (fasted vs. satiated). Means and standard deviations are presented in Table 5

Table 5. Proportion of choices of the 'experimental' over the 'control' gamble for the probability of winning, expected losses and gains across fasted and satiated sessions

	Probability of winning on the 'experimental' gamble		Levels of expected losses on 'experimental' gamble		Levels of expected gains on 'experimental' gamble	
Group	High	Low	Large	Small	Large	Small
Fasted	.77 ± .33	.18 ± .18	.45 ± .25	.62 ± .21	.59 ± .23	.48 ± .20
Satiated	.78 ± .30	.14 ± .13	.46 ± .22	.61 ± .18	.58 ± .20	.48 ± .18

Deliberation Times

There was no main effect of Session [$F(1,30)=1.41$, $p=0.26$], Probability [$F(1,30)=1.90$, $p=0.18$], or Expected Gains [$F(1,30)=0.34$, $p=0.57$], but a significant main effect of Expected Losses [$F(1,30)=8.72$, $p<0.01$]. Participants took longer to choose when the ‘experimental’ gamble was associated with large expected losses compared to small losses. Means and standard deviations are presented in Table 6. There was no significant interaction that involved Session (fasted vs. satiated) ‘Gains Only’ vs. ‘Losses Only’ Trials.

Proportionate Choice

Participants chose the guaranteed options significantly more often on the ‘gains only’ trials compared to the ‘losses only’ trials [$F(1,30)=83.07$, $p<0.001$]. Overall choice was unaffected by Session [$F(1,30)=0.41$, $p=0.53$] and the interaction between session and trial type was non-significant [$F(1,30)=0.85$, $p=0.77$].

Deliberation Times

Participants were significantly faster to choose on the ‘gains only’ trials compared to the ‘losses only’ trials [$F(1,30)=12.34$, $p=0.001$]. Reaction times were unaffected by Session [$F(1,30)=1.11$, p=0.30] and the interaction between session and trial type was non-significant [$F(1,30) = 0.314$, p=0.58].

Table 6. Mean deliberation times (seconds) and standard deviation scores for probability of winning, expected losses and gains across fasted and satiated sessions

	Probability of winning on the ‘experimental’ gamble		Levels of expected losses on ‘experimental’ gamble		Levels of expected gains on ‘experimental’ gamble	
Group	High	Low	Large	Small	Large	Small
Fasted	1.64 ± .73	1.67 ± .64	1.73 ± .74	1.58 ± .61	1.65 ± .65	1.66 ± .68
Satiated	1.81 ± 1.01	1.95 ± 1.18	1.94 ± 1.14	1.83 ± 1.03	1.90 ± 1.15	1.86 ± 1.03

Affective Shifting Task

Reaction Times

There was a significant main effect of Stimuli [$F(1,33)= 15.26$, $p < 0.001$], and Condition $F(1,33)= 5.38$, $p < 0.05$, but no significant effect of Session [$F(1,33)=0.25$, $p = 0.617$]. There were no significant interactions between: Session and Condition [$F(1,33)= 1.76$, $p = 0.194$], Session and Stimuli [$F(1,33)= 1.34$, $p = 0.26$], Condition and Stimuli [$F(1,33)= 0.48$, $p = 0.49$], or between Session, Condition and Stimuli [$F(1,33)= 0.08$, $p = 0.78$].

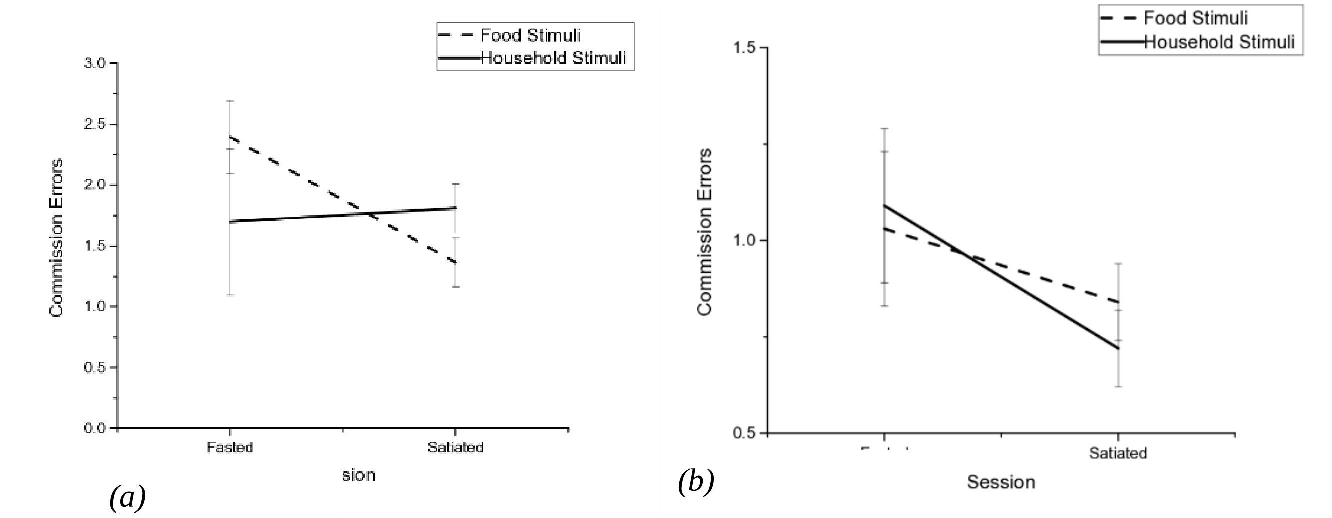
Reaction times (RTs) for food stimuli were shorter (*M*=462.65, *SD*=57.89) than for household items (*M*=482.02, *SD*=56.70). Non-shift trials also had shorter RTs (*M*=468.44, *SD*=57.55), compared to shift trials (*M*=476.24, *SD*=57.04).

Errors of Commission

There was a significant main effect of Session [$F(1,33)= 5.39$, $p < 0.05$] but not of Stimuli [$F(1,33)= 0.15$, $p = 0.69$]. There was also a significant main effect of Condition [$F(1,33)= 43.5$, $p < 0.001$]. The interaction between Session and Stimuli was not significant [$F(1,33)= 2.88$, $p = 0.10$], nor was the interaction between Session and Condition [$F(1,33)= 0.27$, $p = 0.610$], or Stimuli by Condition [$F(1,33)= 0.16$, $p = 0.695$]. However there was a significant interaction between Session, Stimuli, and Condition [$F(1,33)= 4.82$, $p = p < 0.05$].

More commission errors were made during the fasted session (*M*=1.55, *SD*=0.89), than during the satiated session (*M*=1.19, *SD*=0.82). Participants also made a higher number of commission errors for shift (*M*=1.41, *SD*=1.02), compared to non-shift conditions (*M*=0.14 *SD*=0.81).

Bonferroni post hoc comparisons to explore the Session by Stimuli by Condition interaction showed that there was no difference in the number of commission errors made towards household items between fasted and satiated sessions, for either shift (p= 0.33) or non-shift (p=0.23) blocks. There was also no difference in commission errors towards food stimuli for fasted or satiated sessions during the non-shift block (p = 0.44). However, there was a significant difference in the number of commission errors in response to food stimuli during the shift blocks ($p < 0.05$). There was a higher number of commission errors in response to food stimulus during fasted (*M*=2.39, *SD*=2.21) compared to satiated sessions (*M*=1.36, *SD*=1.48), see Figure 7.



(a)
Shift

(b)
Non shift

Figure 7. Mean number of commission errors made during the Affective Shifting Task for food and household stimuli across fasted and satiated sessions. Presented separately for *(a)* Shift condition, *(b)* Non-shift condition. Error bars represent standard error.

Errors of Omission

There was no main effect of Session [$F(1,33)=0.62$, $p = 0.44$] or Stimuli [$F(1,33)=0.005$, $p = 0.95$]. However, there was a significant main effect of Condition [$F(1,33)= 6.17$, $p < 0.05$]. The interaction between Session and Stimuli was not significant, [$F(1,33) = 0.88$, $p = 0.36$], nor was the interaction between Stimuli and Condition [$F(1,33)= 0.25$, $p =0.62$], nor the interaction between Session, Stimuli, and Condition [$F(1,33)= 0.42$, $p = 0.517$]. There was a significant interaction between Session and Condition [$F(1,33)= 7.52$, $p < 0.05$]. Participants made more errors of omission during shift blocks (*M*=1.06, *SD*=0.90), compared to non-shift blocks (*M*=0.77, *SD*=0.87). The Session by Condition interaction was explored using Bonferroni adjusted comparisons and revealed that participants made more errors of omission during shift blocks when satiated ($p < 0.05$). However, there was no difference in omission errors between shift and non-shift blocks when fasted ($p = 0.44$).

Relationship between Questionnaire and Behavioural Measures

Change scores between satiated and fasted sessions were calculated for the commission errors made during the AST, and for the number of boxes opened during the FW condition of the IST. Change scores for the state questionnaire measures were also calculated (state anxiety, blood glucose, and hunger). Correlations between these variables were then calculated. However, there was no significant correlation between the questionnaire measures and difference scores for the IST and AST. See Table 7.

Table 7. Pearson correlations between the IST and AST difference scores (satiated minus fasted) and state changes in Anxiety, Blood Glucose and Hunger.

	Difference between Satiated and Fasted Sessions	
	IST Boxes Opened FW Condition	AST Commission Errors
Demographic Variables		
Age (years)	-0.12	-0.10
Body Mass Index (BMI)	-0.28	-0.07
Trait Measures		
UPPS-P	-0.22	-0.02
BDI	0.09	0.00
EDE-Q	-0.07	-0.12
Trait-STAI	-0.01	-0.19
State Measures (Difference Scores)		
State-STAI	0.16	-0.04
Blood Glucose	0.14	0.16
Hunger	0.17	-0.00

Note: All correlations were non-significant, $P > 0.05$. IST = Information Sampling Task; AST = Affective Shifting Task; UPPS-P = the Impulsive Behaviour Scale; BDI = Beck Depression Inventory; EDE-Q = Eating Disorder Examination Questionnaire-6; STAI = State-Trait Anxiety Inventory

2.3. Discussion

This study aimed to examine the effect of short-term fasting on tasks measuring four components of impulsivity: action inhibition, delay aversion, risky decision-making, and reflection impulsivity. Results showed that when fasted, subjects made significantly more errors of commission for pictures of food compared to household stimuli during the shift blocks of the Affective Shifting Task (AST). This indicates that fasting impaired participant's ability to inhibit their actions. However, fasting did not affect performance during the Temporal Discounting or Choice x Risk Tasks. This indicates that delay aversion and risky decision-making are unaffected by fasting. Finally, contrary to our initial predictions, participants took longer and opened more boxes in the Fixed Win (FW) condition of the Information Sampling Task (IST) when fasted.

Participants exhibited more errors of commission for food stimuli during the AST when fasting, compared to when satiated, indicating a deficit of action inhibition. However, this only occurred during the shift blocks, suggesting an interaction with the demands of the task. Furthermore, there was no difference in response times between fasted and satiated sessions. The AST was the only task in the battery that used stimuli directly relevant to the motivational state of the participants when fasted and this might underlie the fact that increased impulsivity was only evident in this limited aspect of this one task.

By contrast, short-term fasting did not affect delay aversion. Fasted participants were no less likely to choose to delay the receipt of a monetary reward than when they were satiated. One explanation for this finding is that participants may have viewed the on-screen choices of potential financial gain as being more distant than the immediately available pictures of food in the AST, thus allowing them to be more objectively assessed (Rachlin, 2009). Previous studies have shown that it is possible for individuals to show different discount rates for different types of reward. For example, nicotine deprivation can lead to a steeper discounting rate for cigarettes but not monetary rewards (Mitchell, 2009). An alternative explanation is that the degree to which an individual discounts future rewards might be a trait characteristic (Odum, 2011), which is therefore stable over time (Kirby, 2009; Mischell, 1992) and less affected by motivational state.

Participants showed no difference between fasted and satiated sessions for the different probabilities of winning, different magnitudes of expected losses, and expected gains on the Choice x Risk Task. This indicates that risky decision-making was not influenced by short-term fasting. This finding is in contrast to previous research that found increased risky decision-making for food, water, and money following four hours of food and water deprivation (Levy, Thavikulwat, & Glimcher 2013). However, this difference could be related to differences in reward. Participants in the current study received points rather than food, water, or money which may be differentially affected by fasting. Food and water are primary reinforces and are biologically more rewarding compared to points. Additionally, exploratory analysis of fasted state on risk preferences in previous research revealed a small effect (5% change) that appeared to be related to the baseline characteristics of the included sample (Levy, Thavikulwat, & Glimcher 2013). Participants who were risk averse in the satiated state were less risk averse when fasted. However, the opposite was true for individuals who were more risk seeking in the satiated state, who were more risk averse when fasted. Therefore the average shift towards more risky decision-making in the fasted session was suggested to be due to more participants included in the sample being more risk averse when satiated. This indicates that the effect observed in the current study may reflect the sample characteristics, and not generalise to the population, or compare to other studies.

Our findings are also inconsistent with those of Symmonds and colleagues, (2010), who found that risky decision-making decreased when fasted participants were fed to satiation. However, this study involved exclusively male participants (Symmonds et al., 2010), whereas, the participants in the current study were all female. Hence, gender differences might account for the inconsistent results, especially considering that males and females have been shown to respond to fasting differently (Uher, 2006). More subtly, the effect on risky decision-making in the previous study was only significant immediately after a satiating meal but not one hour later (Symmonds et al., 2010). Most participants in the current study were likely to have eaten over an hour prior to the satiated experimental session, suggesting that these results may not be inconsistent with those found by Symmonds and colleagues. Future studies of this type should ensure that satiated participants have eaten a standardised meal immediately prior to the testing session.

Participants opened more boxes and made fewer errors in the Fixed Win (FW) condition of the IST when fasted, indicating a decrease in reflection impulsivity. By contrast, there was no fasted/satiated difference for the Decreasing Win (DW) condition, which demands that participants also monitor the number of boxes that are opened. Various factors may contribute to this difference. Firstly, the task requires shifting attention between decision making (deciding which box colour is in the majority) and box-opening. In the DW condition, there is an external prompt to this switch from the ever-decreasing number of points displayed on the screen, something that is absent in the FW case. Recent research has demonstrated that fasting affects some forms of shifting, particularly with cue-induced craving (Piech, 2009), and that 18 hours of fasting exacerbates set-shifting difficulties on a rule change task (Bolton et al., 2014). This might therefore underpin the enhanced sampling. A related possibility is that the fasted subjects may have found it hard to step back from the detail of opening each box individually to see the 'whole picture' to make a decision. The term 'central coherence' is used to refer to the ability to combine information into the 'bigger picture' rather than focussing only on the finer detail, and has been found to be impaired under fasting conditions (Pender et al., 2014). As for shifting, the inherent emphasis in DW on the decreasing number of points could have cued the subjects into decision-making and hence eliminated the effect of fasting on box opening seen in the FW condition. Further experiments would be necessary to resolve the underlying cause of the IST results.

One limitation of the current experiment is the inability to address whether the differences found between fasted and satiated sessions are due to a primary effect of lowered blood glucose on brain function, or a secondary effect of hunger (induced through fasting) influencing motivation or fatigue. It is possible that blood glucose plays a role here, however, some previous research indicates that changes in cognition can be independent of blood glucose and may be mediated by other factors, such as hunger (Pollit, 1983), and could be controlled by homeostatic mechanisms not assessed in the current study (Cryer, 1981).

Green and colleagues (1995) have previously found that although there was a significant difference between self-reported hunger for fasted and satiated sessions, task performance was not affected. This indicates that subjective measures of hunger may not always relate to differences in task performance. The tasks in the current study for which there were non-significant findings may not have been sensitive enough to detect subtle differences in performance that could occur as a result of fasting (Green, 1995). Further research is needed in order to examine the role of subjective hunger on cognition and to separate out the influence of primary and secondary effects of fasting on cognitive performance.

Therefore the results of Experiment 1 require further investigation to understand the mechanisms underpinning the effect of decreased reflection impulsivity on the IST and to better understand the effect of short-term fasting in healthy participants. The degree to which the current results for the IST can be attributed to decreased impulsivity when fasted, or increased compulsivity should be investigated. The results of increased box opening when fasted could be related to a difficulty shifting set or seeing the bigger picture (Bolton et al., 2014; Pender et al., 2014). Therefore a further study should be conducted which is designed to replicate the results of the IST, and further investigate whether the effect found in the current experiment could be due to impaired set shifting or central coherence difficulties.

3. Chapter Three

Does short term fasting influence measures of compulsivity?

The present study aimed to further investigate the effect of fasting on cognitive performance, specifically, to extend the findings of Experiment 1. Results from Chapter 2 (Experiment 1) demonstrated an effect of fasting on two domains of impulsivity; action inhibition and reflection impulsivity. When fasted, participants made more errors of commission, indicative of a deficit in action inhibition. This impairment of action inhibition was most pronounced in the more difficult shift condition of the affective shifting task. Additionally, fasting seemed to influence the amount of information participants sampled before making a decision. However, this was in the opposite direction to the expected effect. Participants opened more boxes in the fixed win (FW) condition of the IST when fasted. That is, they demonstrated less reflection impulsivity when fasted. Together these results show pronounced effects of short-term fasting on tasks assessing different measures of impulsivity. Although these results could be taken to indicate decreased reflection impulsivity when fasted this needs to be replicated before firm conclusions can be drawn. As the degree to which the effect found for decreased reflection impulsivity when fasted could reflect an impairment in other executive functions is still to be determined.

The disrupted task performance when fasted during Experiment 1 (Chapter 2) could be interpreted as involving elements of executive functioning linked to compulsive behaviour. Participants showed increased commission errors for the shift compared to non-shift conditions. This could be attributed to the increased task demands of switching attentional set and overriding previous instructions, or could reflect a difficulty in shifting sets. This difficulty switching from responding to one stimulus to another has been previously demonstrated in fasted healthy controls (Bolton, Burgess, Gilber, & Serpell, 2014; Pender, Gilbert, & Serpell, 2014). This process of changing, or switching between different tasks, rules or mental sets has been widely studied in eating disorders. There is considerable evidence that individuals with AN show inflexible approaches to problem solving and rigid, compulsive patterns of behaviour (Roberts et al., 2007; Dalley, Everitt, & Robbins, 2011). Research by Bolton and colleagues demonstrated that 18 hours of fasting exacerbated set-shifting difficulties on a rule change task (Bolton et al., 2014). This supports research showing that fasting affects shifting, particularly with cue-induced craving (Piech et al., 2009).

There is a specific reason why determining the precise explanation for the findings of chapter 2 is important. Although this type of short-term fasting in a healthy population is not identical to the patterns of food restriction and chronic or intermittent fasting seen in EDs, it could, in part explain some of the discrepancies found between studies that have examined set shifting in an ED population, identified during Chapter 1. If short-term fasting is shown to exacerbate set-shifting difficulties, and participants in the ED studies vary in the degree of short-term fasting, then differences in results between studies could be at least partly a reflection of this. Therefore, it is important to establish the degree to which fasting could influence compulsive responding, such as set-shifting. Tasks assessing attentional set-switching provide a measure of compulsive responding.

Deficits in set-shifting as a result of fasting could explain, in part, why participants in Experiment 1 opened more boxes in the FW condition of the IST when fasted.

Appropriate responding during the IST requires shifting between a box opening mode and a decision-making mode. A deficit in this switch could be attributed to either (1) a specific difficulty shifting from external stimuli (box opening) to internal thoughts (decision making) or (2) a general deficit in self-generated shifting in the absence of any cues. The first type of set-shifting involves switching the allocation of attention between a visual input (stimulus-orientated) and a self-generated (stimulus-independent) thought (Gilbert, Frith, & Burgess, 2005). One way of measuring this attentional allocation, or shift, is to ask participants to attend to task relevant perceptual information (stimulus-orientated phase) or to mentally perform the same task (stimulus-independent phase). During the FW condition of the IST participants are required to keep in mind the task instructions to make a decision, whilst responding to external perceptual stimuli by opening boxes, and therefore this requires a voluntary switch from a perceptual (box opening) mode to making an internal decision (deciding which box colour is in the majority). This is unlike the DW condition in which participants also receive external perceptual information (decreasing points), which could act as a cue to stop opening boxes and make a decision. This ability to flexibly shift attention between internally and externally generated stimuli could be affected by fasting, impairing decision making during the FW condition. This specific aspect of set-shifting can be measured using the Alphabet Task, which assesses stimulus-independent and stimulus-orientated shifting (Gilbert et al., 2008).

Alternatively, the increased box opening during the FW condition of the IST could be attributed to a general difficulty voluntarily shifting between opening boxes and making a decision, due to perseverative type behaviour. This type of voluntary set-shifting is different to that measured by traditional set-shifting tasks as it requires a self-generated, participant driven shift, independent of external cues. Traditional tasks assessing set-shifting difficulties which have been used in EDs, such as the Wisconsin Card Sorting Task (WCST), cue participants when a set-shift is required (Tchanturia et al., 2012). This is similar to the DW condition of the IST in which participants are cued to make a decision by the decreasing points. This difference between the conditions may explain the different findings for the FW and DW conditions. Therefore, a voluntary set-shifting task will be used in the current study to determine whether voluntary set-shifting is affected by fasting (Arrington, & Logan, 2004).

Although previous research has shown that short-term fasting can exacerbate difficulties shifting between rules, fasting has also been associated with impaired global, but stronger local processing, indicative of weaker central coherence (Bolton, Burgess, Gilber, & Serpell, 2014; Pender, Gilbert, & Serpell, 2014). Individuals with EDs, particularly AN, have been shown to have difficulties with central coherence by getting fixated on the detail at the expense of the bigger picture (Lopez et al., 2008). Pender and colleagues found that this ‘difficulty seeing the wood for the trees’ was also present in HCs after fasting for eighteen hours. Participants had improved identification of detail, but worsened identification of global information. Impaired central coherence could also be relevant to the findings from Experiment 1. The IST is programmed so that a 5x5 matrix of individual boxes (local detail) make up a square (global information), which is presented on the screen. During the task participants open each box, and are required to hypothetically ‘step back’ and examine the global information (box colour in the majority) in order to make a decision. If fasting improves local processing at the expense of global processing, this may impair the participant’s ability to step back and make a global decision. It is possible that this did not have an impact in the DW condition as the decreasing points may have served as a constant reminder to assess the global picture, and make a decision earlier. This tendency to focus on the local, at the expense of global processing can be assessed using the Global-Local Task, a measure of central coherence (White, O'Reilly, & Frith, 2009). Previous research into the effect of short-term fasting using the Local-Global task has found that short-term fasting was associated with stronger local, but weaker global processing (Pender, Gilbert, & Serpell, 2014).

The current study aims to examine the influence of fasting on a measure of compulsive responding and to further investigate the results from Experiment 1 by attempting to replicate the results from the IST, and additionally examining the effect of short-term fasting on measures of set shifting and central coherence in healthy participants. This should then provide a clearer understanding of the mechanisms underpinning the results from Experiment 1.

In line with the results from Pender and colleagues, who found that short-term fasting exacerbated difficulties in set-shifting during a rule change task, it is hypothesised that short-term fasting will:

1. Exacerbate difficulties on both measures of set-shifting; the Voluntary Set-Shifting and the Alphabet Task.
2. Additionally, based on Pender and colleagues' findings of stronger local processing and weaker global processing using the Local-Global task, it is expected that short-term fasting will strengthen the detection of local stimuli, and impair the detection of global stimuli.

3. Additionally, the study aims to replicate the findings from the IST, i.e. participants will open more boxes during the fixed win condition of the IST when fasted.

3.1. Method

Participants

A power calculation for a repeated measures, within subject ANOVA with a small effect size (0.25) and 90% power conducted in G*Power indicated a required sample size of 30.Thirty two healthy female volunteers (mean age = 24.6, SD = 7.76, range = 18.05-55.96) were included in the current study. Eligibility criteria and experimental design were identical to Experiment 1.

Procedure

A within-subject repeated measures design was used to compare individuals' scores on four cognitive tasks, at two different time points: once when fasted and once when satiated. The mean time interval between sessions was 7.25 (*SD* = 1.14, range = 5-12). (For detailed description of experimental procedure and questionnaire measures, please refer to Experiment 1.

Measures

Questionnaires

All questionnaires listed below were identical to those described in Experiment 1.

Beck Depression Inventory (BDI–II; Beck, Steer, Ball, & Ranieri, 1996)

The Eating Disorder Examination Questionnaire-6 (EDEQ-6; Fairburn & Beglin, 1994)

The Impulsive Behaviour Scale (UPPS; Whiteside & Lynam, 2001)

Hunger Scale

Mini International Neuropsychiatric Interview (MINI; Lecrubier et al., 1997)

3.1.1. Experimental Tasks

Information Sampling Task (Clark, Robbins, Ersche, & Sahakian; 2006)

The task used was identical to that described in Experiment 1.

Global-Local Task (White, O'Reilly, & Frith; 2009) This task was designed to measure central coherence and has been previously used with adults and children with autistic spectrum disorder (White, O'Reilly, & Frith, 2009) as well as in a fasted healthy group (Pender et al., 2014). Participants are asked to identify two stimuli (letters) that appear on the screen, see Figure 8. The stimuli are five letters (E, H, P, S, & U) presented as a global letter or several smaller letters. Letters are briefly displayed consecutively on the screen, and participants are then told to enter the corresponding letters into the keyboard in the correct order. Feedback is given on each trial for correct and incorrect answers. In the current study, participants completed a total of 4 blocks that began first with five slow practice trials, followed by twenty-five experimental trials consisting of each possible combination of the five letters for the two stimuli (first versus second) in a randomised order. These blocks were completed in the following order: Global-Global (GG), Local-Local (LL), Global-Local (GL), and Local-Global (LG). The proportion of correct trials for both the first and second letter in each block of trials was calculated.

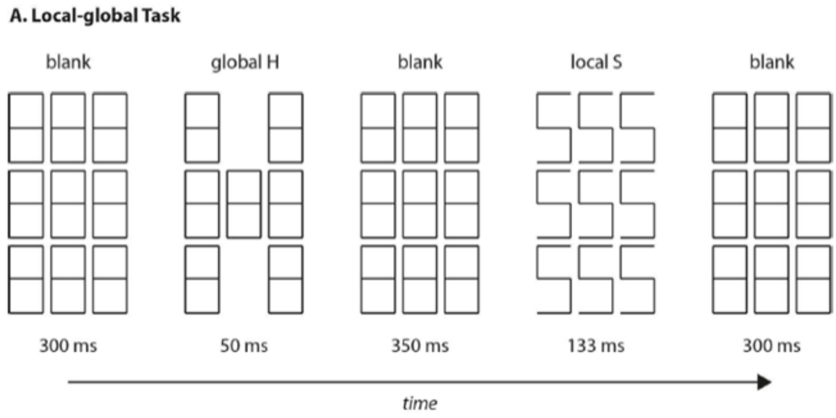


Figure 8. Example trials during the Global-Local Task

Alphabet Task (Gilbert, Bird, Brindley, Frith, & Burgess; 2008)

This task is designed to measure the ability of a participant to switch attention between a visual input (stimulus-orientated) and a self-generated (stimulus-independent) thought. During this task, participants are asked to classify letters of the alphabet presented individually on the screen in alphabetical order according to whether or not they are composed of straight lines (e.g. H) or contain curved lines (e.g. C) see Figure 9. The next letter of the alphabet was presented immediately after each response. There are two phases during the experiment; a Stimulus Orientated phase (SO) in which a stimulus is presented on the screen, and a Stimulus Independent (SI) phase, where participants are required to keep classifying the letters in alphabetical order in the absence of any visual stimulus. During the SI phase participants are required to mentally continue in sequence from the last letter that was presented during the SO phase, classifying self-generated letters by making the appropriate key press. The first SO letter presented at the end of the SI phase would be the next letter in the sequence, assuming that the sequence had been correctly followed. For example, if the SI phase ended with the presentation of the letter S, the SO letter to be characterised would be the letter T. The mean interval between the SO and SI transitions was 7.5 seconds (range of 3-21 seconds).

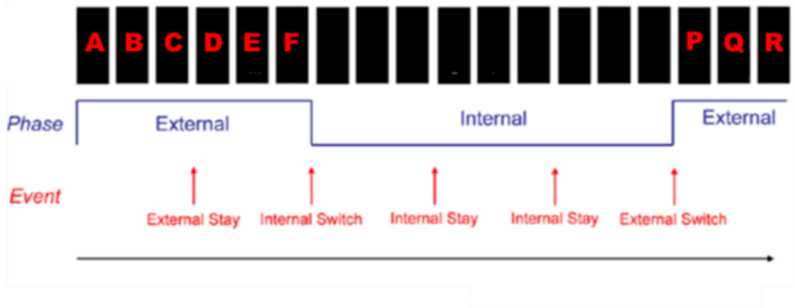


Figure 9. Illustration of the trial sequence during the alphabet task.

Voluntary Set Shifting Task, (Arrington & Gordon, 2004)

This task aims to measure set shifting under voluntary conditions. During this task participants are required to make ‘odd/even’ or ‘high/low judgements on single digits from 1-9 (excluding 5) presented on the screen, see Figure 10. For example, participants are asked whether ‘4’ is ‘higher or lower than 5’ or ‘odd or even’. Participants depress either the ‘d’ and ‘f’ (left hand) or ‘j’ and ‘k’ (right hand) keys with the index and middle fingers. For the high/low task the left finger ‘d’ or ‘j’ is used to indicate ‘lower than 5’. The mapping of task to hand is counterbalanced across participants. There are two phases during the task: an instructed phase in which participants are told which task (decision) to complete, and a voluntary phase in which the participant decides which task to complete (high/low or odd/even judgement). During the voluntary phase participants are instructed to ‘switch between the two tasks as randomly as if you were flipping a coin’.

Figure 10. Example trial during the voluntary set shifting task.

3.2. Results

Experimental Tasks

Information Sampling Task

All participants had accuracy scores over 60% and therefore all were included in subsequent analyses. The dependent variables of number of boxes opened, number of incorrect judgements (errors) and latency of box opening (number of boxes opened divided by time to make a decision) were all analysed.

Group Analysis of Boxes Opened

A mixed model ANOVA with the within subject factors of Condition (FW, DW) and Session (fasted, satiated) and the between subject factor of Order (FW-DW, DW-FW) was conducted on average number of boxes opened. There was a significant main effect of Condition [$F(1,32)=62.56$, $p<0.001$], such that participants opened more boxes in the FW condition than in the DW condition. There was no significant main effect of Session [$F(1,32)=0.14$, $p=0.71$], and no significant interaction [$F(1,32)= 0.98$, $p=0.33$]. There was no significant effect of Order either in the fasting [$F(1,30)= 0 .51$, $p= 0.48$] or satiated group [$F(1,32)= 1.29$, $p= 0.27$]. Means and standard deviations are displayed in Table 8.

Group Analysis of Latency (Box Opening)

Average latency of box opening was used as a proxy for level of motivation on the task. This was calculated by dividing the total time opening boxes prior to making a decision by the number of boxes opened. A mixed model ANOVA was conducted with average latency of box opening as the dependent variable. There was a significant main effect of

Condition [$F(1,32)=14.97$, $p<0.01$] such that participants were slower to open each box than in the FW condition (Table 8). There was no significant main effect of Session [$F(1,32)=0.89$, $p=0.35$], and no significant interaction [$F(1,32)=0.62$, $p=0.44$]. There was no significant effect of Condition Order either in the fasting [$F(1,32)= 0.03$, $p= 0.86$] or satiated group [$F(1,32)= 3.04$, $p= 0.86$].

Group Analysis of Error Data

Analysis of error data with a mixed model ANOVA showed a significant main effect of Condition [$F(1,32)=10.20$, $p<0.05$], whereby more errors were produced in the DW condition. There was no significant main effect of Session [$F(1,32)=0.23$, $p=0.63$], and no significant interaction [$F(1,32)=0.19$, $p=0.66$]. There was no significant effect of Condition Order either in the fasting [$F(1,32)= 1.95$, $p=0 .17$] or satiated group [$F(1,32)= 1.15$, $p= 0.29$]. See table 8 for mean scores and SDs.

Table 8. Mean difference and standard deviation scores across fasted and satiated sessions for the IST

Measure	Fast		Satiated	
	DW Condition	FW Condition	DW Condition	FW Condition
Boxes Opened	9.15 ± 3.30	15.24 ± 5.65	9.41 ± 4.12	14.50 ± 5.96
Latency	13.17 ± 4.89	15.77 ± 5.99	14.38 ± 7.35	16.31 ± 6.71
Errors	2.18 ± 1.61	1.30 ± 1.21	1.97± 1.31	1.30 ± 1.23

Global-Local Task

Two participants’ data were not collected for this task due to experimental error and six participants with scores greater than three standard deviations from the group mean, which indicated extreme outliers, were excluded resulting in a total sample size of twenty four.

Accuracy

A 2 x 4 x 2 ANOVA with the within subject factors of Session (fasted, satiated), Trial Type (Global-Global, Local-Local, Global-Local, and Local-Global) and Letter Order (letter 1, letter 2) for the proportion of correct responses was conducted. There was a significant main effect of Trial Type [$F(1,24)=30.59$, $p<0.001$] and Letter Order [$F(1,24)=35.05$, $p<0.001$] but no significant main effect of Session [$F(1,24)=0.01$, $p=0.91$]. Participants had higher accuracy when the trial type did not require a switch (GG and LL vs. GL, and LG) and for the first compared to second letter. There was a significant Trial Type x Letter Order interaction [$F(1,24)=19.96$, $p<0.001$]. The significant main effects of Trial Type, Letter Order, and interaction term were not explored further as they are not pertinent to the main experimental hypothesis. Means and standard deviations are presented in Table 9.

Table 9. Mean difference and standard deviation scores across fasted and satiated sessions

	Fast		Satiated	
	1st Letter	2nd Letter	1st Letter	2nd Letter
Global-Global	0.88 ± 0.13	0.90 ± 0.12	0.88 ± 0.07	0.91 ± 0.07
Local-Local	0.93 ± 0.07	0.90 ± 0.10	0.89 ± 0.08	0.87 ± 0.13
Global-Local	0.88 ± 0.14	0.63 ± 0.21	0.87 ± 0.11	0.64 ± 0.17
Local-Global	0.80 ± 0.12	0.74 ± 0.22	0.84 ± 0.13	0.74 ± 0.20

Alphabet Task

Three participants' data were not collected due to experimental error. Therefore, twenty nine participants were included in data analysis for this task.

Analysis of Reaction Times

A repeated measures 2 x 2 x 2 ANOVA was conducted with the dependent variables of: Session (fast, satiated), Phase (SO, SI), and Trial Type (non-switch, switch) for RTs. Results showed a significant main effect of Phase [$F(1,29)=26.17$, $p<0.001$], a significant main effect of Trial Type [$F(1,29)=67.60$, $p<0.001$], such that participants were quicker to respond to SO compared to SI trials and are quicker for non-switch compared to switch trials. There was a significant interaction between Phase and Trial Type [$F(1,29)=7.55$, $p<0.05$]. However, there was no main effect of Session [$F(1,29)=1.79$, $p=0.19$] and there were no other significant interactions. Means and SDs are presented in Table 10.

Table 10. Mean difference and standard deviation scores across fasted and satiated sessions for the Alphabet Task

	Fast		Satiated	
	SO Condition	SI Condition	SO Condition	SI Condition
Switch	880 ± 225	1015 ± 274	867 ± 210	960 ± 214
Non-Switch	714 ± 106	752 ± 112	691 ± 102	731 ± 126

Voluntary Set-shifting Task

Three participants' data were not included due to experimental error during data collection, hence sample size for these analyses was twenty nine.

A 2 x 2 x 2 x 2 ANOVA with the within subject factors of Session (fast, satiated), Task (low-high, odd-even), Trial Type (non-switch, switch) and Phase (cued, voluntary) was conducted on reaction times (RTs).

Reaction Times

There was no significant main effect of session, [$F(1,29)= 0.23$, $p=0.64$] but a significant main effect of Task, [$F(1,29)= 21.37$, $p<0.001$], Trial Type [$F(1,29)= 71.71$, $p<0.001$], and Phase, [$F(1,29)= 9.52$, $p<0.01$]. RTs were quicker for low-high judgements ($M=0.69$, $SD=1.20$ versus. $M=0.75$, $SD=1.60$), non-switch trials, ($M=0.66$, $SD=1.20$ versus. $M=0.75$, $SD=1.60$), and when cued, ($M=0.70$, $SD=1.37$ versus. $M=0.74$, $SD=1.49$). There was a significant Trial Type by Phase interaction, [$F(1,29)=16.87$, $p<0.001$]. All other interactions were non-significant ($p>0.05$).

Switch Count

A paired samples t-test revealed no differences between total switch count (the number of voluntary switches made) in the fasted compared to satiated session ($t(29)=0.62$, $p=0.54$).

Physiological Analysis

Blood Glucose

Pairwise comparisons revealed a significant difference for blood glucose levels between fasting and satiated sessions ($t(32)= -7.73$, $p<0.001$). Blood glucose levels in the fasted session ($M=4.66$, $SD=0.50$) were lower than in the satiated session ($M=6.29$, $SD=1.35$).

Correlations between Self-Reported Hunger and Blood Glucose Levels

There were no significant correlations between blood glucose and self-reported hunger on the fasted session ($r(32)=-0.140$, $p=0.445$), or on the satiated session ($r(32)=-0.254$, $p=0.160$).

Exploratory Analysis

To identify whether there were any significant differences between the characteristics of the two samples, pairwise comparisons were completed for the following variables: Age, Blood Glucose Fast, Blood Glucose Satiated, Hunger Rating Fast, Hunger Rating Satiated, UPPS-P, BDI, and EDE-Q. There was a significant difference between the samples of Experiment 1 and 2 for Blood Glucose in the fasted session and Blood Glucose in the satiated session only ($p<0.001$), see Table 11. Mean blood glucose levels in Experiment 1 were lower for both satiated and fasted sessions compared to those in Experiment 2.

Table 11. Comparison of sample characteristics of Experiment 1 and Experiment 2

	Experiment 1 (*n*=33)	Experiment 2 (*n*=32)			
	Mean (SD)	Mean (SD)	*t*	df	*P*
Age (years)	25.42 (8.26)	24.56 (7.76)	0.44	63	0.67
Blood Glucose Fast	4.06 (0.51)	4.66 (0.50)	-4.77	63	**<0.001**
Blood Glucose Satiated	4.90 (0.87)	6.29 (1.35)	-4.95	63	**<0.001**
Hunger Rating Fast	55.33 (13.15)	50.23 (13.06)	1.56	62	0.12
Hunger Rating Satiated	31 (8.22)	28.81 (7.18)	1.35	63	0.18
UPPS-P	85.18 (11.55)	87.17 (11.85)	-0.67	60	0.51
BDI	5.15 (4.87)	6.44 (5.67)	-0.98	63	0.33
EDE-Q	7.97 (6.45)	7.45 (5.29)	0.35	63	0.73

3.3. Discussion

The aim of the current study was to further investigate the findings of Experiment 1 that showed increased box opening in the FW condition of the IST when participants were fasted. The study aimed to replicate the observed effect found in Experiment 1 for the IST, and to examine whether this effect could be attributed to (a) decreased reflection impulsivity, (b) a difficulty shifting between an external box opening and internal decision making mode, (c) a general difficulty in self-generated set-shifting, or (d) increased local processing at the expense of global processing as a result of fasting. The results showed no effect of fasting on measures of reflection impulsivity, set-shifting, or central coherence. The results are not consistent with previous research that demonstrated exacerbated set-shifting difficulties when fasting, and strengthened local, but impaired global processing, indicative of weaker central coherence (Bolton, Burgess, Gilbert, & Serpell, 2014; Pender, Gilbert, & Serpell, 2014).

This inconsistent pattern of results may be due to differences between Experiment 1 and 2 in regards to the included samples, task battery, or time of testing. Levy et al (2013) noted that, although on average, short-term fasting seemed to increase risky decision making, these results appear to be related to the specific sample. Participants who were risk-seeking in the satiated state were more risk averse when fasted and participants who were more risk averse when satiated were then less risk averse when fasted. As the majority of participants included in the sample were risk averse, this weighted the average towards an increase in risky decision-making when fasted. As the samples used in both Experiment 1 and 2 are random selections of the population it is possible that a variation in the characteristics of included participants between the studies may have contributed to the inconsistent findings.

Additionally, participants were aware that blood glucose levels would be checked in order to confirm adherence to the fasting component of the study. The significant difference between blood glucose levels between fasted and satiated sessions indicates that participants successfully completed the fasting component of the study. However, this may have caused a subject-expectancy effect whereby the participant unconsciously altered their behaviour in order to act according to how they thought they should after a period of fasting. Though it is not clear why this should be different between Experiment 1 and 2 other than the possibility that the task battery used in Experiment 1 may have conveyed the purpose of the study more clearly due to the strong emphasis on gambling tasks, whereas the purpose of the tasks in Experiment 2 were not so obvious. However, the specific effects found for commission errors in the Affective Shifting Task, and only increased box opening in the FW condition of the IST in Experiment 1, are hard to account for with this explanation.

A recent systematic review by Benau and colleagues (2014) notes that the time of day that a participant is tested can have an influence on the effects of short-term fasting. Benau and colleagues (2014) suggest that the effects of short-term fasting on measures of memory, mental rotation, and attention seem to be particularly affected when testing takes place in the afternoon. The time of testing may therefore have differed between Experiment 1 and 2, which may have affected the results. Additionally previous studies using a fasting paradigm have provided a meal (Symmonds, et al., 2010). This ensures that all of the participants in the satiated session will be satiated. However, the current experiment did not provide food prior to testing on the satiated session. Participants may have missed breakfast or lunch and therefore could have been hungry during the satiated session. The current experiment looking at the effect of short-term fasting on measures of central coherence used the same Global-Local task (White et al, 2009) as Pender et al (2014). However, the current study had a sample size of thirty-two, in comparison to the sample size of sixty participants in Pender and colleagues (2014) study. The failure to replicate may have been due to this smaller sample size, as it may have affected the power to be able to detect any significant effects.

Although there were significant differences between the self-reported hunger, and blood glucose in the fasted compared to satiated session, surprisingly there was no correlation between hunger and blood glucose. This suggests that hunger and blood glucose may independently contribute to impaired cognitive performance. A limitation of the study is the inability to separate out the separate contribution of lowered blood glucose, hunger, or other correlated physiological processes not measured. Metabolic processes as a consequence of short-term fasting, such as lowered blood glucose, have been hypothesised to cause of impairments in cognition (Van der Zwaluw, Van de Rest, Kessels, & De Groot, 2014). However, impairments in cognitive performance have also been demonstrated to be independent of blood glucose (Ståhle, Ljungdahl Ståhle, Granström, Isaksson, Annas, & Sepp, 2011). Blackman, Lewis, Polonsky, Spire and Towle, (1990) showed that cognitive impairments emerged between 3.3 and 2.6 mmol/L (millimoles per litre) blood glucose levels. This indicates that the blood glucose levels need to reduce from the normal range of 4.4-6.1mmol/L to below 3.3mmol/L in order for effects to be shown. However, the average blood glucose during the fasted session of the current study only reduced to 4.66mmol/L, so the blood glucose levels of the majority of participants may not have reduced sufficiently to show an effect. The lower mean blood glucose level of 4.06 is still above Blackman and colleagues cut off of 3.3, but would have meant that a larger proportion of participants will have dropped below this level, perhaps explaining the significant results in this study.

Hunger has also been found to be independent of task performance, with significant differences in self-reported hunger found despite no difference in task impairments (Green, Elliman, & Rogers, 1995). This could be due to preoccupation with food and the depleting effect of hunger on cognitive resources. The exact contribution of hunger, separable to blood glucose, on cognitive impairments is unclear, but it is noteworthy that blood glucose was uncorrelated with self reported hunger in the current study. Therefore further studies are warranted that look at the unique relationship between hunger and cognition, separate to lowered blood glucose as a result of fasting.

One approach to the study of hunger and cognitive performance is to look naturalistically at the relationships between task impairments and self-reported hunger in the absence of instructed food deprivation. This could help identify whether variance in task performance could be accounted for by self-reported hunger.

4. Chapter Four

What are the relationships between naturalistic self-reported hunger and measures of compulsivity and impulsivity?

Experiment 1 (Chapter 2) demonstrated an effect of experimentally induced fasting on measures of action inhibition, and reflection impulsivity. Results for reflection impulsivity were in an unexpected direction; when fasted, participants were less impulsive and sampled more information before making a decision. Therefore, Experiment 2 (Chapter 3) was designed to further investigate this effect and aimed to replicate, explain and extend these findings. However, Experiment 2 found no effect of fasting on measures of reflection impulsivity, measures of set-shifting or central coherence. This was in contrast to the results of Experiment 1 and prior research (Pender et al., 2014; Bolton et al., 2014). These null findings could be attributable to a number of different factors including differences in sample characteristics between the two experiments (Chapter 3). The subjective experience of hunger was lower and blood glucose was higher in Experiment 2 compared to Experiment 1. It is possible that in order to document observable effects on tasks measuring executive functioning, blood glucose needs to drop below a critical level. This is a hypothesis put forward by Blackman, Lewis, Polonsky, Spire and Towle, (1990) who demonstrated a critical level of below 3.3 - 2.6 mmol/L for blood glucose related impaired cognitive performance.

Alternatively, self-reported hunger could independently account for changes in performance across fasted and satiated sessions. Loeber, Grosshans, Herpertz, Kiefer, and Herpertz, (2013) demonstrated separable effects of self-reported hunger and blood glucose on performance. Hunger, but not blood glucose, was related to impairments in response inhibition on a GoNo Go task using food stimuli. This indicates that the effect of hunger and blood glucose may be independent. Experiments 1 and 2 were limited by the inability to separate the contribution of hunger and/or lowered blood glucose, and the results did not allow for conclusions to be drawn about the unique contribution of hunger on task performance. Although Experiment 1 did not show a correlation between hunger and impaired task performance this could have been due to a lack of variance in hunger scores. Experiment 1 and Experiment 2 experimentally induced hunger through fasting for 18 hours and therefore naturalistic variations in hunger were not captured. It is likely that the experience of fasting may vary between individuals. Some individuals may have a higher tolerance to hunger than others, due to the subjective nature of the concept, and this may vary during a period of fasting (Green, Elliman, & Rogers, 1997). It is difficult to separate the contribution of the subjective feeling of hunger from the biological state of fasting (Uher, Treasure, & Campbell, 2002). Therefore alternative approaches looking at the correlation between hunger and task performance, in the absence of fasting, are warranted.

Existing literature on the relationship between hunger and cognitive functioning has demonstrated that impaired executive functioning is linked to high levels of hunger. Jones and Rogers (2003) examined the effect of hunger on cognitive performance in dieters. The authors concluded that the cognitive impairments found in the dieters was due to depleted cognitive resources. They suggest that this was a result of a preoccupation with hunger and food that interrupted and hindered task performance.

Previous research (outlined in Chapter 1) has demonstrated differences between healthy controls and individuals with an eating disorder on tasks measuring set-shifting ability (Roberts, Tchanturia, Stahl, Southgate and Treasure, 2007). However, in contrast to the previous experiment (Chapter 3) existing research has mainly used the Wisconsin Card Sorting Task (WCST) and the Trail making Task (TMT). Although it has been established that the WCST relies on executive functioning, it is likely that multiple cognitive processes are involved in task execution including elements of bottom up and top down control (Head, Kennedy, Rodrigue, & Raz, 2009). This limits the specific conclusions that can be drawn about the unique contribution of disrupted set-shifting on task performance independently of other processes. However, although the tasks used in Chapter 3 are hypothesised to more adequately measure set-shifting, using different tasks limits comparisons between current and previous research in the field of EDs. Therefore, the first of the experiments reported in this chapter aims to understand the relationship between hunger and set-shifting ability measured through more traditional tasks, such as the WCST and TMT allowing for comparisons to previous literature in ED populations. If there is a relationship between hunger and measures of compulsivity used in the ED literature this could be a potential confound or explanatory factor for findings in previous research. Similarly, it would suggest that hunger is a key variable to assess in future clinical studies when assessing interventions or differences between ED and non–ED populations.

The second experiment reported in this chapter will investigate whether there is a relationship between hunger and measures of impulsivity used in Experiment 1 (Chapter 2). Hunger, as assessed by the Three Factor Eating Questionnaire (TFEQ, Stunkard & Messick, 1985) has been shown to be correlated with attentional impulsivity, measured though self-report (Lyke & Spinella, 2004). Additionally, Nederkoorn, Guerrieri, Havermans, Roefs, and Jansen, (2009) found an interactive effect of hunger and impulsivity on real world food buying, suggesting a possible relationship between hunger and impulsivity.

4.1.1. Hunger and compulsivity

Due to the finding that hunger can impair executive functioning, and building upon the research of Pender et al (2014), the first experiment reported in this chapter will employ a naturalistic design to examine whether there are relationships between self-reported hunger, measures of central coherence, and measures of set shifting. The WCST and TMT, along with the previously used Global-Local task, will be used in order to allow for comparisons with previous literature.

It is expected that

1. Lower accuracy scores for the Global-Local Task, will be predicted by higher self-reported hunger. Specifically, it is hypothesised that participants experiencing higher levels of hunger will be less accurate when having to switch from the detail (local) to the bigger picture (global) indicating weaker central coherence similar to that observed in EDs (Roberts et al, 2013).
2. It is also expected that there will be a higher number of perseverative errors on the WCST with increased hunger.
3. It is also predicted that performance on the TMT (B-A time and B-A accuracy) will be less flexible with increasing hunger.

4.1.2. Hunger and impulsivity

Additionally the relationship between hunger and measures of impulsivity will be investigated in a second experiment in a separate sample run in parallel.

It is hypothesised that, in line with the findings from Experiment 1,

1. Impairments in action inhibition as measured with the previously used affective shifting task will increase with higher levels of self-reported hunger.
2. The number of boxes opened during the fixed win condition of the information sampling task will be higher for increasing hunger.
3. There will be no relationship between risky decision making and hunger.
4. There will be no relationship between the delay participants are willing to tolerate to receive a reward and self-reported hunger.

4.2. Method

Participants and Design

Two separate experiments are reported in this chapter. In Experiment 3a, a naturalistic design was used to examine the relationship between self-reported hunger and measures of set-shifting and central coherence. Experiment 3b was run in parallel to examine the relationship of self-reported hunger and four measures of impulsivity: reflection impulsivity, action inhibition, risky decision making, and delay aversion. The experiments were run in separate samples to avoid any fatigue or priming effects that could have resulted from the combination of the battery of tasks.

Power calculation for a bivariate correlation with a medium effect size (0.45) and 80% power conducted in G*Power indicated a required sample size of 36. However, due to the anticipated exclusions associated with the student sample being tested, a sample size of 50 participants was decided upon.

A total of one hundred female participants were therefore recruited via the University College London (UCL) subject pool and via poster advertisements placed around campus. Fifty participants self selectively signed up for Experiment 3a and fifty for Experiment 3b Eligible participants were female, aged 18-50, and had a BMI >18.5. Participants were excluded if: they were currently being treated for any serious medical or psychological condition, they had any history of neurological illness, head injury, or self-reported experience of mental illness. Each experiment lasted sixty minutes and participants were reimbursed £7.50 for their time. This study was approved by the university research ethics committee. Participants gave written informed consent and a full debrief was provided at the end of the study.

Procedure

Participants were provided with an information sheet and, after providing informed consent were asked questions relating to demographic information. Participants were then weighed using scales accurate to 0.05kg and height was measured using a portable stadiometer in order to accurately calculate BMI. Next participants completed the behavioural tasks in a randomized and counterbalanced order. Following task completion participants were asked to fill in the questionnaire measures using the online Qualtrics software. Questionnaires were completed last in order to minimise any potential social desirability or priming effects.

Behavioural Tasks

4.2.1. Experiment 3a

Global-Local Task

Central coherence was measured using the Global-Local task (White, O'Reilly, & Frith, 2009) described in detail in Chapter 3.

The Trail Making Task, (Reitan 1958)

The TMT see Fig. 11, was used to assess attentional set shifting ability due to its use in the ED literature, and the fact that it is validated for the measurement of set shifting ability (Sanchez-Cubillo et al, 2009). PEBL software (Piper et al 2012) was used to run the task. During this task participants are asked to complete two sections, A and B. Part A requires participants to join together a series of numbered dots in numerical order from 1 to 10. In Part B there are dots labelled with letters (A, B, C etc.) and numbers. Participants are required to alternate between numbers and letters whilst linking the dots, e.g. 1-A-2-B-3-C etc. Response time and accuracy are measured separately for Part A and B. The outcome measure of cognitive flexibility is then calculated as B minus A time and accuracy in line with Corrigan and Hinkeldey, (1987).

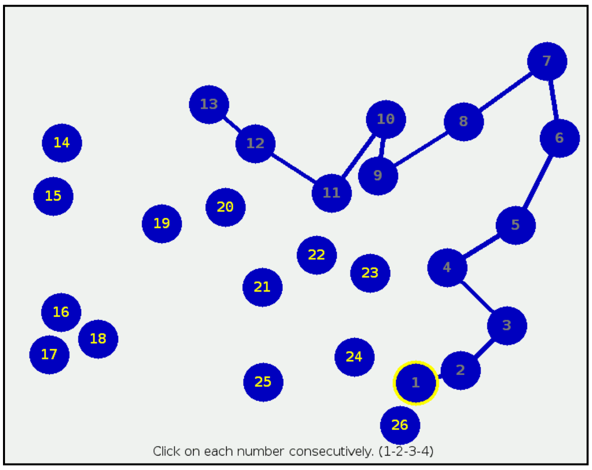


Figure 11. Screenshot of the TMT during Part A

The Wisconsin Card Sorting Task, (Fox et al., 2013).

The WCST (see Fig. 12) was used as a further measure of set-shifting ability and perseverative/compulsive responding, (Grant and Berg, 1948). This task was presented using the PEBL software (Piper et al 2012). During this version of the WCST, four cards are presented simultaneously on screen and vary in terms of shape, colour, and number of shapes depicted. On each trial a fifth card is presented at the bottom of the screen and participants are instructed to match this card to one of the four. Participants are not instructed on which rule to follow (i.e. whether to order by shape/colour/number) but must use the incorrect/correct feedback to guide choices. Measures taken during this task include the total number of correct judgements and perseverative responses/errors. This reflects the number of times the participant carried on with the same rule, and was either correct or incorrect in their perseverance. This version of the sorting task has been validated by Fox, Mueller, Gray, Raber, and Piper (2013).

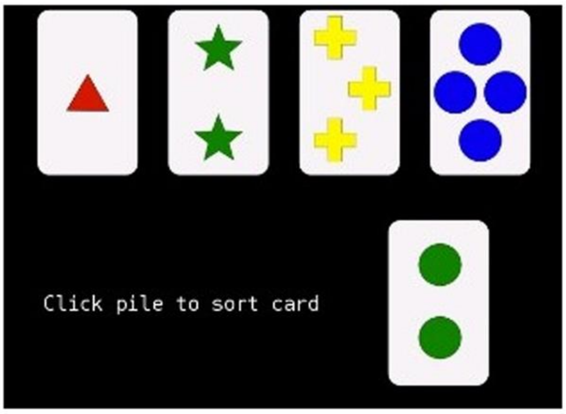


Figure 12. Screenshot during the WCST.

4.2.2. Experiment 3b

Behavioural Tasks

The tasks used were identical to those described in Experiment 1, (Chapter 2) and included the: Information Sampling Task (Clark, Robbins, Ersche, & Sahakian; 2006), Temporal Discounting Task (TDT, Pine, Seymour, Roiser, Bossaert, Friston, Curran, & Dolan, 2009), Choice x Risk Task (CRT, Rogers, Tunbridge, Bhagwagar, Drevets, Sahakian, & Carter, 2003), and the Affective Shifting Task (AST, modified from Murphy, Sahakian, Rubinsztein, Michael, Rogers, Robbins, & Paykel, 1999).

Self-report measures

All measures used in the current study have been described in detail previously, (Chapters 2 and 3) and included: The Grand Hunger Scale, and the Eating Disorder Examination Questionnaire.

Analysis Plan

Descriptive statistics for demographic information and questionnaire measures for both Experiment 3a and 3b are displayed in Table 12. All statistics are presented as mean ± standard deviation.

Experiment 3a

Behavioural data for the TMT, WCST, and Global-Local task were inspected for outliers. Z scores more than three standard deviations from the mean were excluded from further analysis. Across the whole sample three participants were excluded as extreme outliers were identified on all three tasks. This resulted in an overall sample size of *N* = 47. Correlational analysis was run between hunger scores, and all outcome measures for the TMT, WCST, and Global-Local Task. The main outcome measures entered into the bivariate correlation were: Global letter identification accuracy, Local letter identification accuracy, Global to Local letter identification accuracy, Local to Global letter identification accuracy, WCST Errors, WCST Perseverative Responses, WCST Perseverative Errors, TMT A-B Time, and TMT A-B Accuracy.

Experiment 3b

Behavioural data for the experimental tasks was individually inspected for any Z scores more than three standard deviations from the mean and any outliers were excluded from further analysis. This resulted in the following exclusions on each task: Affective Shifting Task (one outlier identified, *N* = 49), Temporal Discounting Task (two participants scored less than 80% on the catch trials, *N* = 48), Information Sampling Task (*N* = 50), and the Choice x Risk Task (*N* = 50). In order to examine the relationship between self-reported hunger and the four domains of impulsivity, the main outcome measures for each task were entered into a bivariate correlation along with hunger. The main outcome measures were: the of number of boxes opened during the Fixed and Decreasing Win conditions of the IST, total commission and omission errors during the AST, number of experimental compared to control gambles for the Choice x Risk task, and number of sooner rather than later options chosen during the Temporal Discounting task.

4.3. Results

Table 12 shows demographic data for the sample in the two experiments.

Table 12. Descriptive statistics for demographic information and questionnaire measures.

	Experiment 3 *(a)*	Experiment 3 *(b)*
Demographic Variables		
Age (years)	19.63 ± 1.05	23.6 ± 5.54
Body Mass Index (BMI)	20.82 ± 2.71	21.24 ± 2.54
Questionnaire Measures		
Grand Hunger Scale	91.98 ± 49.10	96.19 ± 51.72
EDE-Q	2.67 ± 4.84	1.11 ± 0.83

Correlational Analyses

Experiment 3a

Correlations were calculated between self-reported hunger scores and all nine outcome measures. Pearson's *r* values for the correlation with hunger were as follows: Global letter identification accuracy (r = -0.164), Local letter identification accuracy (r = 0.177), Global to Local letter identification accuracy (r = -0.189), Local to Global letter identification accuracy (r = 0.071), WCST Errors (r = 0.065), WCST Perseverative Responses (r = -0.102), WCST Perseverative Errors (r = -0.069), TMT A-B Time (r = 0.117), and TMT A-B Accuracy (r = 0.150). None of these correlations were significant, (all p values > 0.213). Correlations between outcome measures are displayed in Table 13.

Experiment 3 b

Correlations were calculated between self-reported hunger scores and all outcome measures. Pearson's *r* values for the correlation with hunger were as follows: boxes opened during the Decreasing Win condition of the IST (*r* = 0.106), Commission Errors on GoNo Go Task (*r* = 0.073), Omission Errors on GoNoGo Task (*r* = 0.075), number of experimental gambles chosen during the CxR task (*r* = 0.071), and number of sooner rather than later choices on the TD task (*r* = 0.025). None of these correlations with hunger were significant (all *p* values > 0.418). However, the correlation between number of boxes opened in the FW condition of the IST and hunger was significant at $p<0.001$ with a medium-large effect size *r* = 0.553. This correlation was positive such that higher hunger was associated with opening more boxes in the FW condition before making a decision. Correlations between outcome measures are displayed in Table 14.

Table 13. *Correlations between set-shifting and central coherence tasks*

	Local accuracy	Global-Local accuracy	Local-Global accuracy	Perseverative Responses	WCST Perseverative Errors	TMT A-B Time	TMT A-B Accuracy
Global accuracy	.19	.12	.42**	-.13	-.25	.15	-.04
Local accuracy		.55**	.52**	.09	.02	-.04	-.06
Global-Local accuracy			.32**	.09	.15	.10	-.21
Local-Global accuracy				.05	.16	.39	.07
Perseverative Responses					.77**	-.29*	.22
WCST Perseverative Errors						-.24	.28
TMT A-B Time							-.39**

*p<0.05, **p<0.01

Table 14. *Correlations between impulsivity tasks*

	DW boxes opened	Commissions	Omissions	Experimental gambles	Smaller-sooner choices
FW boxes opened	.45**	.01	.03	.02	-.11
DW boxes opened		-.05	-.13	-.01	-.13
Commissions			-.24	.11	.05
Omissions				.09	-.06
Experimental gambles					.02

**p<0.01

4.4. Discussion

Employing a naturalistic design, the current study consisted of two experiments which aimed to examine the relationship between self-reported hunger and measures of impulsivity and compulsivity. Experiment 3a aimed to examine the relationship between hunger and four measures of impulsivity: reflection impulsivity, action inhibition, risky decision making, and delay aversion. Experiment 3b aimed to examine the relationship between self-reported hunger and measures of central coherence, and attentional set-shifting.

Hunger and measures of impulsivity

There was a significant correlation between the number of boxes opened during the FW condition of the IST and higher levels of self-reported hunger. However, there was no correlation between hunger and measures of action inhibition, risky decision-making, or delay aversion. The significant finding of higher hunger associated with a higher number of boxes opened during the FW but not the DW condition of the IST could indicate an impact of hunger on performance during the task. This could, in part, explain the inconsistent findings between Experiment 1 and 2 for the IST. If the increased box opening during the FW condition was due to higher hunger in Experiment 1, then the null findings for the IST in Experiment 2 could be a result of lower levels of hunger. However, due to the correlational nature of the current experiment, we cannot tell whether higher hunger is causally related the number of boxes opened. It is possible that a third common factor is involved. In addition, hunger was not correlated to measures of action inhibition. This is somewhat surprising, given that experiment 2 showed poorer performance on one measure of action inhibition in the fasting state (fasted individuals made more errors of commission for pictures of food, compared to household stimuli during the shift blocks of the AST). The lack of a significant relationship between hunger and action inhibition in the current experiment may indicate that the effect of fasting on action inhibition may not be directly related to hunger but some other process related to fasting. Alternatively it is possible that features of the experimental design contributed to the null finding. These will be discussed below.

Hunger and measures of compulsivity

Self-reported hunger was not correlated with perseverative errors, nor with responses on the WCST. Additionally self-reported hunger was not correlated with longer B-A time, or worse B-A accuracy on the TMT. There was no relationship found between self-reported hunger and letter identification accuracy scores during the Global-Local Task for any of the outcome variables: global letter identification, local letter identification, global to local letter identification, and local to global to local letter identification.

These null findings do not support previous research that has found a relationship between hunger and cognitive performance on tasks measuring impulsivity and compulsivity (Wesnes, Pincock, Richardson, Helm, & Hails, 2003; Jones and Rogers 2003). However, there could be a number of factors contributing to this finding.

Firstly, although the tasks used to measure set-shifting have demonstrated differences between individuals with and without an eating disorder, the WCST for example was designed for individuals with brain lesions (Berg, 1948). This could mean that the task is not sensitive enough to detect subtle differences induced as a result of hunger. Therefore the null findings could be related to the insensitivity of the task rather than an absence of an effect (Lieberman, 2003).

Secondly, the naturalistic design could have meant that there was not sufficient variation in the participants' hunger levels. The variance in the hunger covered in the current study is likely to be small compared to the full range that could be experienced during a period of food deprivation. Participants were not aware that the purpose of the study was to examine hunger levels and if they had felt hungry prior to the study, they are likely to have eaten, resulting in lower levels of hunger and a reduced range. The sampling method may therefore not have adequately captured the degree of hunger that could potentially be experienced. Therefore, although the null results do not support the hypothesis that higher hunger is associated with greater impairments on tasks assessing set-shifting and central coherence ability, a lack of effect may not disprove the hypothesis. The results could be taken to be consistent with the view of set-shifting and central coherence performance as reflecting a trait in those with an eating disorder rather than a consequence of hunger. However, it has yet to be established the degree to which hunger or starvation could contribute and worsen this performance, as suggested by Pender et al (2014).

Limitations

A limitation of this experiment which may have influenced the results was the sample being studied. A large number of outliers were identified which could have been due to the student population. However, despite the relatively high number of participants who could not be included, the statistical analyses were still sufficiently powered. Future experiments of this type should take the possibility of high levels of outliers into account when conducting power calculations to estimate required sample sizes. Although research supports the view that these tasks measure separate components of impulsivity (Evenden, 1999), it is interesting to note the lack of correlation between any of the impulsivity tasks in the current experiment. However, there was a significant correlation between perseverative errors on the WCST and the B-A TMT time suggesting that both tasks measure aspects of set-shifting.

Furthermore the regulation of hunger signals in the brain is complex and involves many systems (Tataranni et al., 1999). More appropriate indicators of hunger levels that objectively measurable physiological markers, such as hormones like insulin, could provide a more complete understanding. Such measures were not available for the current study but it may be fruitful to include these in future studies alongside self reported hunger.

In summary the current experiments failed to find evidence of a relationship between self-reported hunger and measures of central coherence, two tasks assessing set shifting, action inhibition, risky decision-making, and delay aversion. However, there was a modest correlation between one measure of impulsivity, the number of boxes opened during the fixed win condition of the IST and self-reported hunger. There were a number of limitations associated with the current methodological design. However, the results still contribute to the understanding of hunger and cognition. Together the results from Experiments 1, 2, and 3a and b indicate that fasting and hunger may affect different elements of task performance in a complex and variable manner. The differences observed and the causes of these variable findings warrant further investigation. Researchers in the eating disorders field have suggested that impulsivity in particular is linked to the persistence of abnormal eating behaviours such as bingeing (Steiger, Lehoux, & Gauvin, 1999). However, it is not currently clear how any effects of fasting on impulsivity and compulsivity would relate to abnormal eating behavior, such as bingeing. Previous research into this link suggests a moderating role of impulsivity (Meule, 2003; Jansen et al., 2009; Meule, Lukito, Vogele, & Kubler, 2011). However, further research is needed to begin to understand the mechanism for any link between fasting, impulsivity and eating behavior.

5. Chapter Five

Does impulsivity moderate the relationship between fasting, cravings and ad libitum food intake?

The link between fasting and increased hunger has been well established (Lappalainen, Sjödén, Hursti, & Vesa, 1990). However, Experiments 3a and 3b (Chapters 4) failed to find strong evidence that naturalistic, self-reported hunger was related to impairments on tasks measuring components of impulsivity and compulsivity. This null finding could be attributed, in part, to the experimental design. Participants in Experiment 3a and 3b, in comparison to Experiments 1 and 2, were not instructed to restrict their food intake or undergo a period of food deprivation. It is likely given these instructions that participants experiencing anything more than mild hunger prior to the task will have eaten. The experience of restriction and subsequent deprivation associated with fasting for 20 hours, rather than simply relatively mild hunger, could account for the observed differences between fasted and satiated state found in Experiment 1 and explain the null findings of Experiment 3a and 3b.

Results from Experiment 1 showed that some measures of 'trait' impulsivity were susceptible to changes in the physiological state of the individual. Healthy controls were more impulsive on a measure of action inhibition when fasted. Yet, there was no effect of fasting on measures of risky decision-making or temporal discounting. Findings for reflection impulsivity appeared to show an unexpected *decrease* in impulsivity when fasting. Nevertheless this result was not replicated in Experiment 2 (Chapter 3). The task used to measure action inhibition in Experiment 1 utilised food stimuli, which may have enhanced differences in performance between fasted and satiated states. This would be consistent with findings from the systematic review (Chapter 1) which highlighted that differences between eating disorder groups and healthy controls were most pronounced when tasks used food stimuli. However, the tasks used to measure reflection impulsivity, risky decision-making, and temporal discounting included non-food stimuli. Therefore, the effect of fasting could be more marked when specifically applied to impulsive actions towards food.

'In Chinese, we have a saying: You eat first with your eyes, then your nose, then your mouth'

Wendy Leon, Chef

The enhanced effect when using food stimuli could be due to the fact that food is a primary reinforcer. As the quote illustrates, food selection is mainly guided by the visual system (Laska et al., 2007; Linne et al 2002). The sight of food activates physiological changes that prepare the body for consumption (Wallner-Liebmann et al., 2010), emotional responses linked to the pleasure of consumption (Ouwehand & Papies, 2010), and cognitive processes such as memory retrieval and hedonic evaluation (Berthoud & Morrison, 2008). Many brain regions are activated in response to food pictures and these regions are thought to evaluate the sensory qualities of food, its desirability, and co-ordination of behaviour (Appelhans, 2009; Kringelbach, 2004). The brain's response to food cues has been shown to be predictive of subsequent food consumption and it is therefore important to understand the factors that could influence these processes (Lawrence, Hinton, Parkinson, & Lawrence, 2012). The acquisition and maintenance of disordered eating has been hypothesised to be related to disruptions in these processes (Schmitz, Naumann, Trentowska, & Svaldi, 2014).

Research has identified that the brain's response to food cues can be modulated by: 1) the saliency and rewarding value of the food stimuli, 2) the physiological state of the individual, and 3) cognitive processes, such as decision-making which can be influenced by individual differences in trait characteristics (Garcia-Garcia, Narberhaus, Marques-Iturria, Garolera, Radoi, Segura, Pueyo, Ariza, and Jurado, 2013).

5.1.1. Saliency of food stimuli

The saliency of a visual food cue is related to its hedonic properties and calorie content (Garcia-Garcia et al., 2013; Batterink, Yokum, & Stice, 2010). Hedonic properties refer to subjective pleasantness or palatability; how much an individual 'likes' the taste of the food. This 'liking' can be dissociated from the concept of 'wanting' food, which describes a motivational drive (Berridge, 1996; Robinson & Berridge, 2000; Wyvell & Berridge, 2000). Together the 'liking' and 'wanting' associated with a food can determine its rewarding value. However, these concepts are dissociable and susceptible to different manipulations (Finlayson, King, & Blundell, 2007). For example, food deprivation increases the reinforcing value, i.e. wanting of food without necessarily affecting liking (Epstein, Truesdale, Wojcik, Paluch, & Raynor, 2003).

The pleasantness or 'liking' of a food stimulus can be assessed through self-report measures. However, the degree of 'wanting' is harder to assess through self-report. The degree to which an individual 'wants' a stimulus is often confused with how much they think they 'like' that stimulus (Finlayson, King, & Blundell, 2007). The very attribution of 'wanting' to a stimulus may alter its sensory aspects into incentives that are desired or wanted. For example, the incentive salience of chocolate may increase as a result of a restrained eater limiting their intake of chocolate. The sensory qualities of the chocolate become more alluring, the colour, texture, and smell instigate a visceral and motivational drive towards that stimulus. This motivational drive can be measured in paradigms that assess the degree to which an individual will work for a rewarding stimulus including food (Ahern et al., 2010). Using this approach, it has been demonstrated that the reinforcing value of food is increased as a result of food deprivation (Bulik & Brinded, 1994; Epstein, Bulik, Perkins, Caggiula, & Rodefer, 1991; Epstein, Truesdale, Wojicik, Plauch, & Raynor, 2003; Futon, Woodside, & Shizgal, 2000). Other paradigms that have been used to measure the degree of 'wanting' related to food stimuli include the individual's willingness to pay (WTP) for a particular item (Plassmann, O'Doherty, & Rangel, 2007). This paradigm measures the financial resources that an individual is willing to give up in exchange for the item that is available. The WTP that is assigned to the item represents its worth to the individual (Plassmann, O'Doherty, & Rangel, 2007).

The motivational saliency of a food cue has also been linked to the experience of craving; the urgent desire or longing for a particular substance such as alcohol, drugs, or food (Meule, Skirde, Freund, Vogele, & Kubler, 2012). Cravings can be distinguished from hunger via the intensity of the experience (Hill, 2007) and are associated with binge eating (Gendall, Sullivan, Joyce, Fear, & Bulik, 1997; Meule, Lutz, Vogele, &

Kubler, 2012). The experience of cravings has also been found to negatively affect cognitive performance (Meule, Skirde, Freund, Vogele, & Kubler, 2012; Kemps et al., 2008). Craving and saliency can be measured through behavioural paradigms that examine how much a stimulus interferes with or facilitates a response (Meule & Kubler, 2014).

5.1.2. Physiological state of the individual

Studies have shown that individuals have a preference for energy rich foods after food deprivation, and rate food items as more pleasant (Drewnowski & Greenwood, 1983; Cabanac, 1979). This suggests that food deprivation may modulate the brain's response when viewing food stimuli. A meta-analysis of functional magnetic resonance imaging (fMRI) studies conducted by van der Lan, Ridder, Viergever, and Smeets (2011) demonstrated differences in brain activation in response to viewing food stimuli in a fasted compared to satiated state. Results showed greater Blood-oxygen-level dependent (BOLD) signal in brain regions involved in emotional processing and decision-making when participants were fasted. This suggests key differences in the way that individuals evaluate and make decisions in response to food when they have been food deprived. Cravings towards food items are hypothesised to be due to an altered physiological state.

Researchers have measured cravings in many different ways including questionnaire and behavioural approaches. One approach is to measure the amount of time an individual spends paying attention to a stimulus. This is a measure of attentional bias, which is theoretically related to craving. For example, a meta-analysis found a modest association between attentional bias and subjective craving across 68 studies of substance users (Field, Munafò and Franken, 2009).

The effects of manipulations of the physiological state of the individual have been investigated using a number of different attentional bias tasks. Previous studies using the food related Stroop task, with fasted healthy controls, have found mixed evidence for colour-naming interference for food words compared to neutral words following short term fasting (Channon & Hayward, 1989). However, the interpretation of the interference effect in food related Stroop tasks is not always clear (De Ruiter & Bosschot, 1994) and may not be entirely a result of an attentional bias (MacLeod, 1991). Results from the Stroop task have previously been used as an indication of impulsivity (see Chapter 1). Increased interference naming the colour when using food words has been linked to increased impulsivity, due to the failure to inhibit incorrect responses, and manage interference. Increased interference during this task could therefore reflect increased state impulsivity as a function of fasting, rather than increased attentional bias, or a combination of both processes.

A validated method to investigate attentional bias (the dot probe task) provides a clearer estimate of attentional bias. In a typical dot probe paradigm, participants are presented with two stimuli on either side of the screen. This is then followed by a probe (a dot, or arrow) in the same location as one of the stimuli. The outcome measure is the time taken for the participant to respond to the probe. Theoretically, the shorter the reaction time, the more facilitated the response, assuming that the participant was looking at the image in the same location as the probe before it appeared. Attentional biases to food items can be measured by time taken to respond following target cues (food), compared to neutral cues (such as household objects). Onset of target presentation can also separate out whether the attentional bias is due to initial engagement (short presentation time, such as 50ms) or maintained attentional engagement or disengagement (longer presentation times of 500ms or more).

Investigations looking at the effect of fasting on attentional bias have used mixed paradigms. Mogg, Bradley, Hyare, and Lee (1998) demonstrated an increased attentional bias towards food words compared to neutral words when healthy participants had fasted for 17 hours. Nijs, Muris, Euser, and Franken, (2010) extended this finding by using pictures of food and neutral items and found that normal weight subjects, when fasted for 17 hours, had an increased attentional bias towards food items compared to neutral items at 100 and 500ms presentation times. This suggests both increased initial and maintained attention. Also in support of this finding, Tapper, Pothos, and Lawrence (2010) found that healthy individuals showed an attentional bias towards food items at 100, 500, and 2000ms presentation times. Loeber, Grosshans, Herpertz, Kifer and Herpertz, (2013) looked at differences between high and low hunger and blood glucose at the time of testing. Participants with lower blood glucose demonstrated an attentional bias at 50ms only. However, there was not a bias towards food stimuli for the high blood glucose group, who were presumably satiated. Additionally, Loeber et al., (2012) failed to find an attentional bias effect after participants had fasted for three hours using the same stimulus presentation time of

50ms. This suggests that longer periods of fasting and/or low blood glucose may be necessary in order to elicit increases in food-related attentional bias.

This attentional bias effect has also been shown to be food specific and sensitive to devaluation; a procedure in which the participant is fed until satiation on a specific food item. Pellegrino, Magarelli, and Mengarelli, (2011) showed that participants who had been fasting for 6 hours had an attentional bias towards all food items, which was then selectively reduced (for devalued food items only) following satiation on the 'devalued' foods. This indicates that the attentional bias could be related to deprivation more than just hunger. For example participants could be biased towards salty foods when salt deprived even if they had just eaten chocolate. This could, in part, explain the null findings of Experiments 3a and 3b in which hunger was naturalistically examined. This is in comparison to Experiment 1 & 2 in which deprivation of all food was enforced through fasting.

Another approach to looking at cravings is to ask the participants about the experience of being exposed to a particular food item. This type of cue-reactivity paradigm measure participants' self-reported 'craving' or desire towards a particular substance including food items (Meule & Hormes, 2015). Effect sizes for cue reactivity paradigms eliciting self-reported cravings in drug research has been shown to be large, and a reliable estimate of craving (Carter & Tiffany, 1999). Self-reported cravings may tap into physiological processes not captured by tasks looking at performance, such as the dot probe task. Researchers have investigated the relationship between cravings elicited during cue reactivity paradigms and real world behaviours such as cigarettes smoked or food consumed (Ferguson, & Shiffman, 2009) Recent research in the field of drug addiction suggests that 'peak provoked craving' (the maximum point of craving reached) provides the most useful measure of cue reactivity for methodological and clinical relevance considerations (Sayette & Tiffany, 2012).

5.1.3. Cognitive Processing

The presence of food items can activate the cognitive processes involved in self-control presumably to enable the individual to regulate intake (Kroese et al., 2009; Van den Bos & De Riddler, 2006). Individual differences in trait characteristics such as impulsivity, can influence the processing of food cues. For example, one study assessed self-reported impulsivity, finding that individuals who were more sensitive to reward had increased neural responses (in the fronto–striatal–amygdala–midbrain network) to images of food (Beaver et al., 2006). Additionally, women high in self-reported impulsivity ate more during a bogus taste test compared to individuals who scored low for impulsivity (Guerrieri, Nederkoorn, & Jansen, 2007). Kekic et al (2014) demonstrated that individual differences in impulsivity could moderate the effects of trans-cranial direct current stimulation (tDCS). Individuals with higher self-reported impulsivity showed a smaller reduction in cravings following a tDCS intervention over the dorsolateral prefrontal cortex, which aimed to reduce cravings. This suggests that there may be a moderating role of impulsivity on cravings.

In addition increased impulsivity has been implicated as a risk factor for overeating (Meule, 2003). Individuals with binge eating, or those that meet the criteria for obesity, have lower inhibitory control in comparison to normal weight individuals (Mobbs, Iglesias, Golay, & Van der Linden, 2011; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006; Rosval et al., 2006 Wu et al., 2013). Additionally, impulsivity has been shown to modulate food intake in healthy weight individuals. Those with low self-control and high restraint had the highest food intake (Jansen et al., 2009; Meule, Lukito, Vogele, & Kubler, 2011). It is thought that overeating can result from the interation between cue elicited impulses or cravings and low inhibition (Appelhans, 2009; Heatherton & Wagner, 2011). Hofmann, Friese, and Roefs, (2009) found that food intake was associated with high affective responses to high calorie food, and this was moderated by low inhibitory control. Similarly, weight gain in a student population after one year was predicted by higher implicit preferences (measured with the Single Category Implicit Association Test) towards high calorie food and low inhibitory control (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). Additionally high reward sensitivity towards food cues predicted intake in obese individuals, and this effect was moderated by low inhibitory control (Appelhans et al., 2011).

This research demonstrates that food intake in the laboratory setting, and in the ‘real’ world, is linked to the rewarding value of the food, and that this can be moderated by one aspect of impulsivity, the individual’s lack of self-control. However, it is not clear how the impact of fasting or food deprivation may interact with these factors. Research has indicated that fasting increases the rewarding value of food, which could serve to increase cravings and enhance the moderating role of impulsivity.

The cognitive behavioural model (CB) of bulimia, (Figure 13) suggests that binge eating arises from strict dieting (Fairburn, 1995). In support of this hypothesis, research has shown that bingeing is often preceded by a period of food restriction (Zunker et al, 2011). However, this relationship is mediated by increased cravings (Engelberg et al., 2005; Castellanos et al., 2009). The possible role of impulsivity, a trait hypothesised to be higher in individuals with bulimia, is not currently considered in the CB model. The investigation of the interacting roles of fasting, food valuation, and impulsivity in the general population could aid the understanding of the factors that could increase the risk of developing disordered eating and explain why many dieters who restrict food intake do not develop binge eating (National Task Force on the Prevention and Treatment of Obesity, 2000).

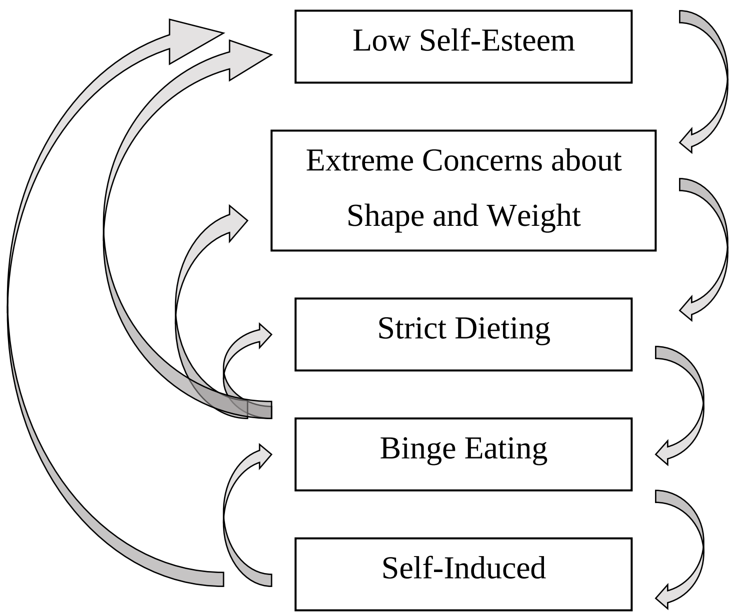


Figure. 13. Fairburn's Cognitive Behavioural Model for the development and maintenance of bulimia nervosa (Fairburn, 1995).

To date there have been no studies that have examined the role of fasting in enhancing the rewarding value of stimuli, nor to determine whether this increase in valuation can predict food intake, and whether there is a moderating role of (lack of) self-control. Therefore the current study was designed to investigate firstly, whether fasting can increase the cravings associated with food, the degree to which an individual 'wants' food, the salience of food, and the amount of food eaten. Secondly, the moderating role of trait impulsivity will be investigated.

It is hypothesised that:

1) The saliency of food items, as measured with an attentional bias task, will be higher when participants are in a fasted compared to satiated state.

2) Interference for food words will be higher in the Stroop task when participants are fasted, compared to satiated.

3) The degree to which participants are willing to work to receive a food reward will be higher when participants are in a fasted compared to satiated state.

4) Participants will consume more food when in a fasted compared to a satiated state.

5) Participants will report a higher level of peak-provoked cravings in response to the sight of food when in a fasted compared to a satiated state.

6) The amount of food eaten when fasted will be predicted by the peak-provoked craving during the fasted session.

7) The above association will be moderated by self-reported lack of self-control.

5.2. Method:

Participants:

Power calculation for a linear multiple regression with a small to medium effect size (0.10) and 80% power conducted in G*Power indicated a required sample size of 100. Participants were recruited from the University College London online subject pool, and via poster advertisements. One hundred and eighteen respondents were initially telephone screened for eligibility. Of these, 15 did not meet the inclusion criteria. The remaining 103 participants were randomised to either fast prior to session 1 or session 2. Screening involved health and psychiatric questions in addition to checking that participants were comfortable consuming the specific foods included as part of the study. Participants with any food allergies, history of mental health or neurological problems, diabetes, currently pregnant or breastfeeding were excluded. Participants received monetary compensation for their time. All participants gave written, informed consent. Ethical approval was granted by an institutional ethics committee (UCL).

Design

The study was a within-subjects repeated measures design to compare scores on behavioural measures at two time points: Once when participants were satiated and once when fasted for 20 hours.

Procedure

Participants attended UCL for two experimental sessions, lasting 90 minutes, separated by 7 days. The mean gap between sessions was 7 days (SD=0.8). Each participant was tested under the same conditions (time of day and laboratory). Sessions were carried out between 4-6pm to control for the influence of circadian rhythms. Both verbal confirmation of fasting and blood glucose levels were obtained from all participants to confirm adherence to fasting instructions.

During one session participants completed the Mini International Neuropsychiatric Interview (MINI; Lecrubier, et al., 1997), three computerised tasks, and one ad libitum food taste test. During the other session participants completed the same computerised tasks and ad libitum taste test in addition to some questionnaires. The order of sessions and tasks was counterbalanced and randomised, with the exception of the ad libitum taste test which was always last.

Measures

Questionnaires

Questionnaires were chosen to record baseline characteristics and to monitor changes across sessions for mood and cravings as induced by the fasting manipulation.

Baseline depressive symptoms and eating disorder psychopathology were recorded using the Beck Depression Inventory (BDI–II; Beck, Steer, Ball, & Ranieri, 1996) and the Eating Disorder Examination Questionnaire-6 (EDEQ-6; Fairburn & Beglin, 1994). Trait impulsivity was measured using the Barratt Impulsiveness Scale (BIS-11; Patton & Stanford 1995).

Subjective hunger and craving questionnaires

The Grand Hunger Scale (Grand, 1968) was used as a between session measure of hunger and administered at the beginning of the session (see Appendix). Additionally craving state was measured with the State Food Cravings Questionnaire (Nijs, Ingmar, Franken & Muris, 2006).

Behavioural Measures

Attentional Bias Task

Pilot Development

Pictorial stimuli were selected for use after piloting (see below). It is hypothesised that pictures provide a more ecologically valid representation of food, compared to using food words, and pictorial stimuli are more strongly related to affective information (De Houwer & Hermans, 1994). Therefore, fifty-four pictures of food items taken from Google images were piloted using Qualtrics online software. This was to ensure that only highly familiar foods with high pleasantness and urge to consume were used for the attentional bias task (see Appendix). Forty-one female participants were asked to categorise each of the fifty-four images for fat content (high/low) per 100 grams, calorie content (high/low) per 100 grams, and type of food (sweet/savoury). Additionally, participants were asked to rate each stimulus from 0 (not at all) to 100 (extremely) for the following statements; how much do you want to eat this food right now? How familiar is this food? How pleasant do you find this food in general? How pleasant would it be to experience a mouthful of this food right now? How much does viewing this food influence your general urge to eat?

Twenty-four images of food items rated highly for familiarity and pleasantness were then selected, twelve from high calorie, and twelve from low calorie groups. There are a balanced number of high and low fat, sweet and savoury food items, see Table 14.

Table 14. Categories of food stimuli balanced for high calorie, high fat, low calorie, low fat, sweet and savoury

	High Fat, Savoury	High Fat Sweet
High Calorie	Pizza	Chocolate
	Cheese (slices)	Cookie
	Crisps	Chocolate Fudge Cake (side)
	Sausage	Chocolate Cake (front)
	Burger	Chocolate ice cream cone
	Chips	Chocolate
	Low Fat Savoury	Low Fat Sweet
Low Calorie	Carrot	Granny Smith Apple
	Mushroom	Strawberry
	Broccoli	Banana
	Cucumber	Orange
	Cauliflower	Watermelon
	Biscuits	Pear

Each of the 24 food stimuli was paired with an image of a neutral item, matched as closely as possible for colour and orientation, see Fig 14 for two example matched pairs.

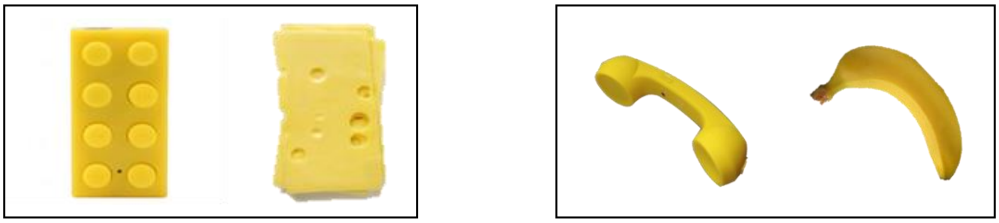


Figure. 14. Example of food-related dot-probe paired stimuli.

Eight different presentation times (100, 200, 400, 500, 1000, 1500, 2000, 25000ms) were piloted (*N*=40) and 2 final presentation times were selected on the basis of the strongest attentional bias towards food cues (400, 2000ms).

Main Task

Each trial started with a fixation cross displayed in the centre of the screen for 1,000ms (Fig. 15). This was then replaced by a pair of pictures for either 400, or 2000ms. The ten practice trials were followed by 156 experimental trials. Of these there were 96 critical trials of food-neutral pairs. Each picture appeared both on the left and right of the screen with a probe (arrow) appearing behind both types of picture in a counterbalanced and randomised order. The probe consisted of an arrow pointing upwards or downwards and participants were asked to respond as quickly but accurately as possible with the ‘k’ key for an upwards pointing arrow, and the ‘m’ key for a downwards pointing arrow using the index and middle finger on their dominant hand.

Reaction times were recorded and attentional bias scores were calculated. Reaction times under 100ms and 3 standard deviations from the individual’s mean following the offset of stimuli were considered to be outliers and excluded from further analysis.

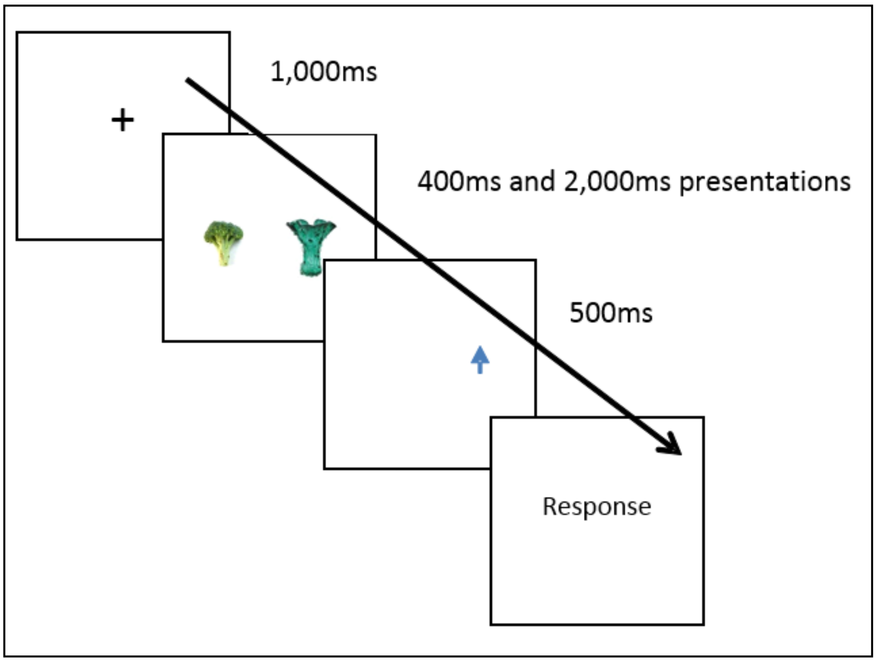


Figure. 15. Example trial during the Attentional Bias Task.

Food Stroop Task

The Food Stroop was comprised of a practice task followed by three parts, administered in a randomised and counterbalanced order. Participants were firstly familiarised with the instructions and completed a practice task in which they named the text colours of colour words. During the first part of the Food Stroop, participants viewed neutral, non-food words. During the second part, participants viewed words of common low calorie foods. During the third part, participants viewed words of common high calorie foods. There were a total of 16 words in each part, presented a total of 5 times each (240 trials in total). Words were matched for syllables and length to neutral words and to each other (see Table 15). For each part, neutral, high and low calorie words were presented in three different text colours (red, blue, or green). Participants were instructed to respond as quickly and accurately as possible by pressing the response key coloured in the corresponding colour to the text colour.

Reaction times, errors and correct responses were recorded for each trial. Reaction times less than 100ms and over 3 standard deviations from the individual's mean were excluded, along with incorrect responses. The average response time and number of correct responses for each category was then calculated.

Table 15. Words used for the Stroop task

Neutral Words	High-Calorie Words	Low-Calorie Words
valley	cake	apple
building	brownie	berries
stone	candy	vegetables
sweater	chips	carrot
telephone	cheesecake	peas
picture	chocolate	grapefruit
door	cookie	banana
table	Fudge	lettuce
envelope	cupcake	salad
pencil	donut	broccoli
lamp	pie	spinach
window	caramel	fruit
calendar	ice cream	melon
flower	cheese	celery
tree	milkshake	peppers
mountain	pizza	cucumber

Willingness to Work Task

The Willingness to Work task (WTW) was a novel paradigm designed to measure the value a participant attaches to an item, and is similar to the Willingness to Pay task (WTP), whilst avoiding using money as a valuation system.

The maximum amount that an individual will pay for an item (WTP) has been used as an estimation of the value of that item. However during the WTP procedure, an individual must bid a monetary amount on an item that has an objective value in the real world. This knowledge of the objective value of the item could interfere with the participant's subjective valuation. Therefore, the current study used the amount participants were willing to work for an item as a marker of value.

Pilot Development

In order to assess the feasibility of the WTW task, a pilot version was compared to the standard WTP task. Pilot participants (*N*=11) were asked to complete both the WTP and the WTW in a counterbalanced and randomised order, and then asked some questions about the experience. Overall participants were willing to work and/or pay for food and non-food items. However, all participants felt that the objective value and quantity of food depicted in the photographs influenced how much they would be willing to pay but not how hard they were willing to work. Additionally, participants reported that they understood the WTW task and they found the food to be generally quite appetising. On the basis of this pilot work the WTW was then selected and is described in full below.

Main Willingness to Work Task

Participants were initially told that they would be asked how much they were willing to work for a particular item shown on screen which could be a food or a neutral item. However, first they would be shown what they would be bidding with. Participants were asked to depress the space bar as many times as they could within a 10 second period. They were told that only trials in which they depressed the space bar over 70 times in 10 seconds would count as a bid. They were then given another practice trial.

Participants were instructed that they would be bidding against the computer in multiples of one, corresponding how many 10 second times they would be willing to work for the item from 0-10. Participants were told that only one of the bids from each session would be selected at random by the programme. The programme would then generate a number between 0-10. If the amount that the participant bid was lower than this number then the computer would win the bid and they would receive nothing. However, if the random number was lower than the participant's bid then the participant would be asked to perform the work in order to receive the item. For example if a bid of 3 was made then they would need to complete 3, 10-second button pressing trials. Participants were also told that despite the bid they made, they would have to wait the total time it would take to complete all ten trials. Therefore in the above example the participant would complete 30 seconds of button pressing and then wait 70 seconds before receiving the reward. This was to control for any potential bias from participant's delay aversion, which might otherwise lead participants to make low bids.

In total there were 30 food images and 30 neutral items presented in a random order, for a total of 60 trials. Participants were given an unlimited amount of time to decide how much they wanted to bid and asked to input a number between 0 and 10, before pressing enter.

Peak Provoked Craving

During this task participants were presented with three bowls of food (Maryland chocolate chip cookies, lightly salted Kettle chips Cadbury dairy milk buttons) each weighing 50 grams. After 1 minute in the presence of these foods (cue exposure) prior to consumption, participants were asked to indicate on a 0-100mm Visual Analogue Scale (VAS) 'At this moment in time how much do you want the cookies/chocolate/crisps?' in addition to 'At this moment in time how pleasant do you think the cookies/chocolate/crisps taste?'. Participants were then asked to sample each of the foods and rate how pleasant each of the foods tasted. Following this, participants were again asked 'At this moment in time how much do you want the cookies/chocolate/crisps?' and 'At this moment in time how pleasant do you think the cookies/chocolate/crisps taste?'. The peak provoked craving is the measure of 'wanting' during cue exposure for the satiated and fasted sessions.

Ad Libitum Food Intake

Following the cue exposure paradigm participants were told that they were allowed to eat as much as the leftover food as they wanted, as the food would have to be disposed of. They were also told that they would be unable to take any food away with them. After one minute the researcher told the participant that they needed to go and check on the next participant, and the current participant was left alone in the room with the food. Once the participant had left, the remaining food was weighed to calculate amount consumed.

5.3. Results

Attentional Bias Task

Attentional bias scores were calculated by subtracting congruent from incongruent trials. This resulted in the dependent variables of Food Bias Score at 400msecs and 2,000msecs and Neutral Bias Score at 400msecs and 2,000msecs. *Z* scores were calculated and inspected for outliers that were more than 3 standard deviations from the mean. Nine exclusions resulted in a sample size of ninety-four.

A within subject repeated measures (2 x 2 x 2) ANOVA with Session (fasted, satiated), Stimuli, (food, neutral) and Duration (400, 2000ms) was run. There was no main effect of Session [$F(1, 93)=2.63$, $p= 0.11$], Stimuli [$F(1, 93)=0.16$, $p= 0.69$] or Duration [$F(1, 93)=0.89$, $p= 0.77$].

There were no significant interactions found for Session*Duration [$F(1, 93)=1.93$, $p= 0.17$], Stimuli*Duration [$F(1, 93)=0.001$, $p= 0.98$], or Session*Stimuli*Duration [$F(1, 93)=2.77$, $p= 0.10$]. However there was a Session*Stimuli interaction [$F(1, 93)=11.48$, $p<0.001$]. Pairwise comparisons revealed that participants had significantly higher ($p<0.001$) attentional bias scores towards Food Stimuli in the fasted (*M* = 4.29, *SD* = 20.35) compared to satiated Session (*M* = -1.29, *SD* = 23.84), see Figure 16. However, the pattern of results was in the opposite direction for neutral stimuli. Significantly higher ($p<0.001$) attentional bias scores were seen in the satiated (*M* = 17.36, *SD* = 57.17) compared to fasted Session for neutral stimuli (*M* = 7.31, *SD* = 70.74).

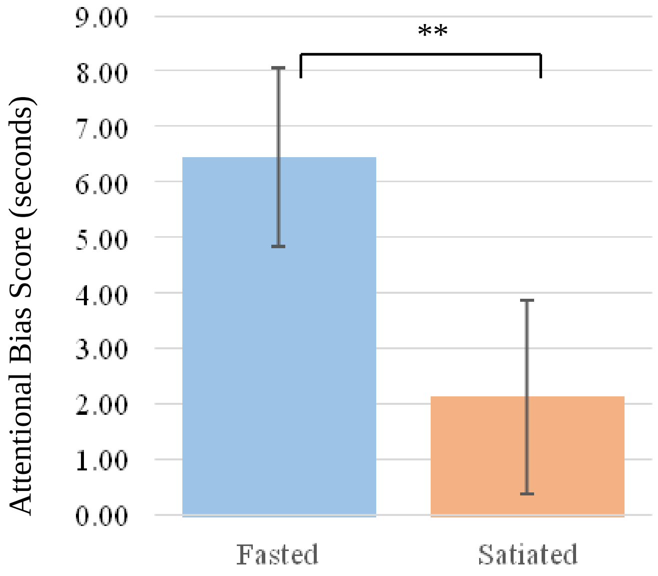


Figure 16. Graph to show mean attentional bias towards food in the fasted compared to the satiated session. Error bars represent standard error.

Food Stroop

Z scores were computed and inspected for outliers more than three standard deviations from the mean. However no outliers were identified. Due to experimental error nine sessions were not recorded leading to the exclusion of nine participants. The final sample size was ninety-four.

A within subject repeated measures ANOVA (2 x 3) with Session (fasted, satiated), and Stimulus (neutral, low calorie, and high calorie) was run. There was no main effect of Session on RT [$F(1,93)=2.25$, $p= 0.14$]. However there was a main effect of Stimuli [$F(1, 93)=8.76$, $p< 0.001$], and a Session by Stimuli interaction [$F(1, 93)=5.31$, $p<0.05$].

Comparisons to investigate the main effect of Stimuli showed a significant difference between neutral stimuli and high calorie stimuli ($p<0.001$), and between neutral stimuli and low calorie stimuli ($p<0.001$), but no significant difference between high and low calorie stimuli ($p=0.91$). Means and and standard deviations for RTs ($M \pm SD$) were the following: neutral words (0.58 ± 0.08), high calorie words (0.60 ± 0.09), and low calorie words (0.60 ± 0.10).

There was a significant interaction between Session and Stimuli, (Fig. 17). When fasting, participants took longer to respond to high and low calorie stimuli compared to neutral stimuli, but this difference was not present when satiated.

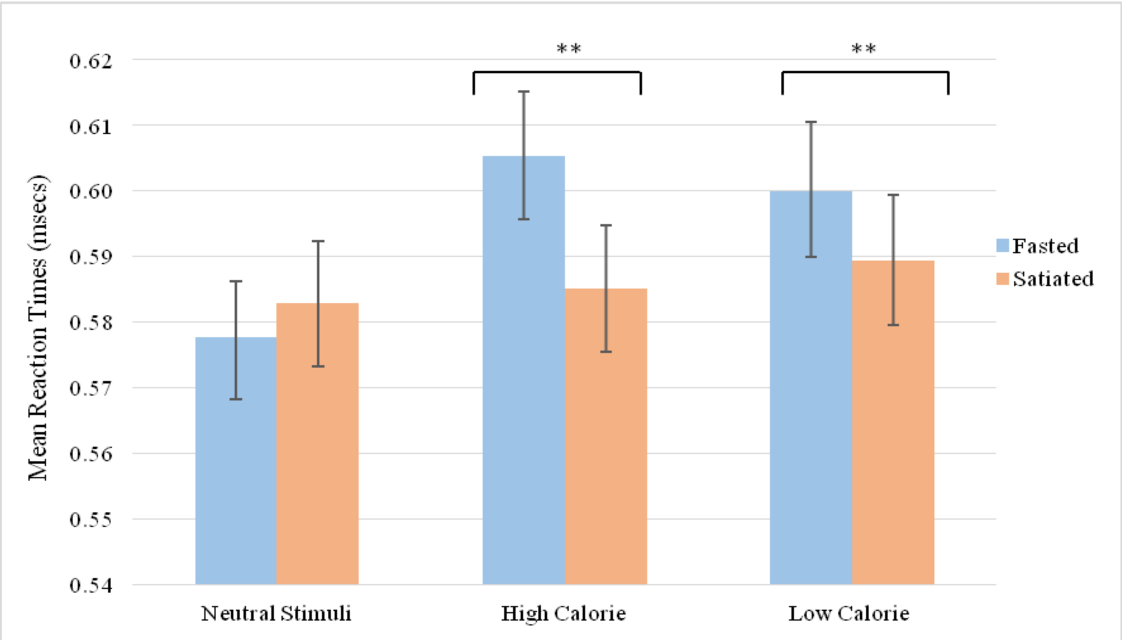


Figure 17. Comparison of the mean reaction times between fasted and satiated sessions for neutral, high calorie and low calorie items. Error bars represent standard error.

Willingness to Work

A within subject (2x2) repeated measures ANOVA, with Session (fasted, satiated) and Stimulus (neutral, food) was run. There was a significant main effect of Session [$F(1, 73)=15.52$, $p < 0.001$], Stimulus, [$F(1, 73)=196.88$, $p < 0.001$], and a significant interaction between Session and Stimulus, [$F(1, 73)=62.64$, $p < 0.001$].

Overall, participants bid higher 'willingness to work' for food items compared to neutral items ($p<0.001$). Participants also bid higher 'willingness to work' for food items in the fasted compared to satiated session ($p < 0.001$), and for the neutral items in the satiated compared to fasted session ($p < 0.05$), see Fig. 18.

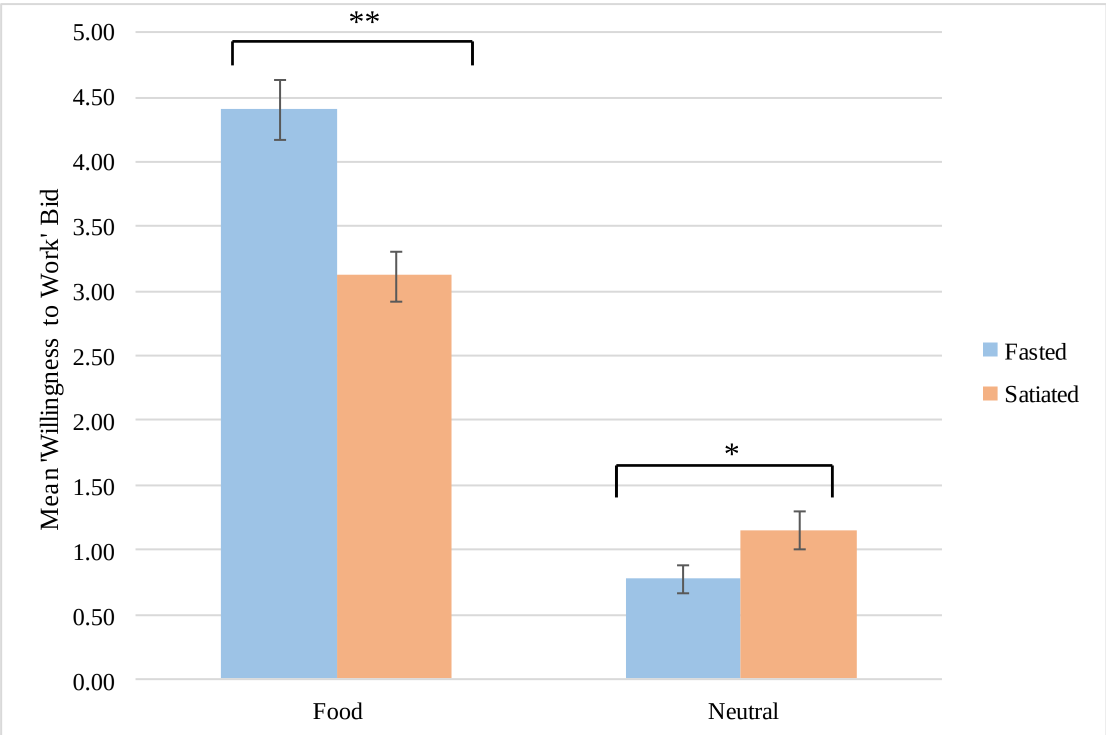


Figure. 18. Comparison of the mean WTW bid between fasted and satiated sessions for food and neutral items. Error bars represent standard error.

Peak Provoked Craving

A (2x3) repeated measures ANOVA, with session (fasted, satiated) and stimulus (crisps, chocolate, biscuits) was run. There was a significant main effect of Session, [$F(1, 102)=105.42$, $p< 0.001$], but not Stimuli [$F(1, 102)=2.64$, $p=0.74$]. There was a significant interaction between Session and Stimuli, [$F(1, 102)=4.31$, $p< 0.05$].

In the fasted session, participants' peak provoked craving (PPC) towards biscuits (*M* = 72.63, *SD* = 26.34), was significantly higher compared to crisps, (*M* = 65.72, *SD* = 29.20), and chocolate (*M* = 63.97, *SD* = 31.33) ($p< 0.01$). However there were no significant differences in peak provoked cravings between crisps, (*M* = 41.20, *SD* = 27.88), chocolate (*M* = 47.03, *SD* = 28.90), and biscuits (*M* = 46.05, *SD* = 29.91) in the satiated session, see Fig 19.

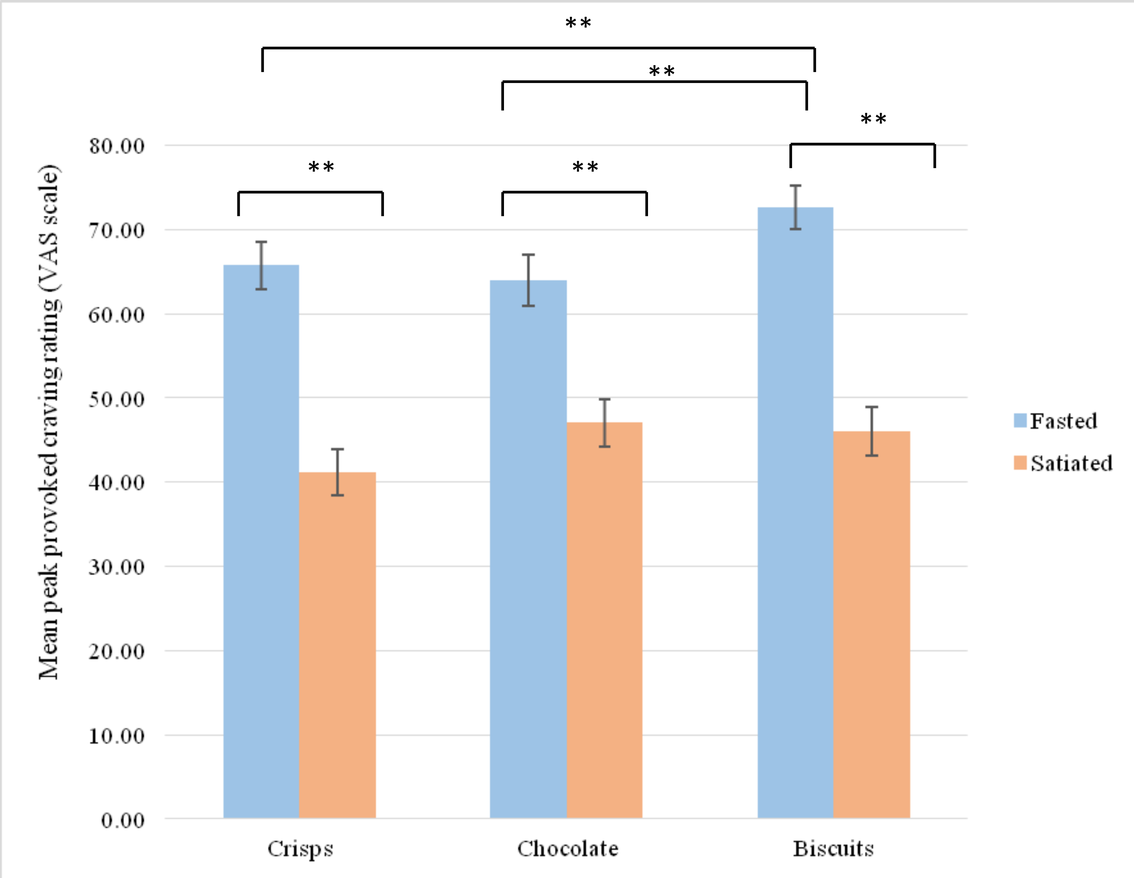


Figure. 19 Mean peak provoked craving ratings for crisps, chocolate, and biscuits across fasted and satiated sessions. Error bars represent standard error.

Ad Libitum Food Intake

A within subject (2x3) repeated measures ANOVA, with session (fasted, satiated) and stimulus (crisps, chocolate, biscuits) was run. There was a significant main effect of Session [$F(1, 101)=44.91$, $p< 0.001$] and Stimuli [$F(2, 202)=9.49$, $p< 0.001$] but no interaction between Session and Stimuli [$F(2, 202)=1.53$, $p= 0.22$].

Participants consumed a higher total quantity (measured in grams) of crisps, chocolate, and biscuits in the fasted compared to satiated state ($p< 0.001$), see Fig 20. Overall, participants consumed a higher quantity of biscuits compared to crisps ($p < 0.001$), and chocolate ($p < 0.01$). There was no significant difference in the quantity of chocolate compared to crisps, ($p = 0.15$).

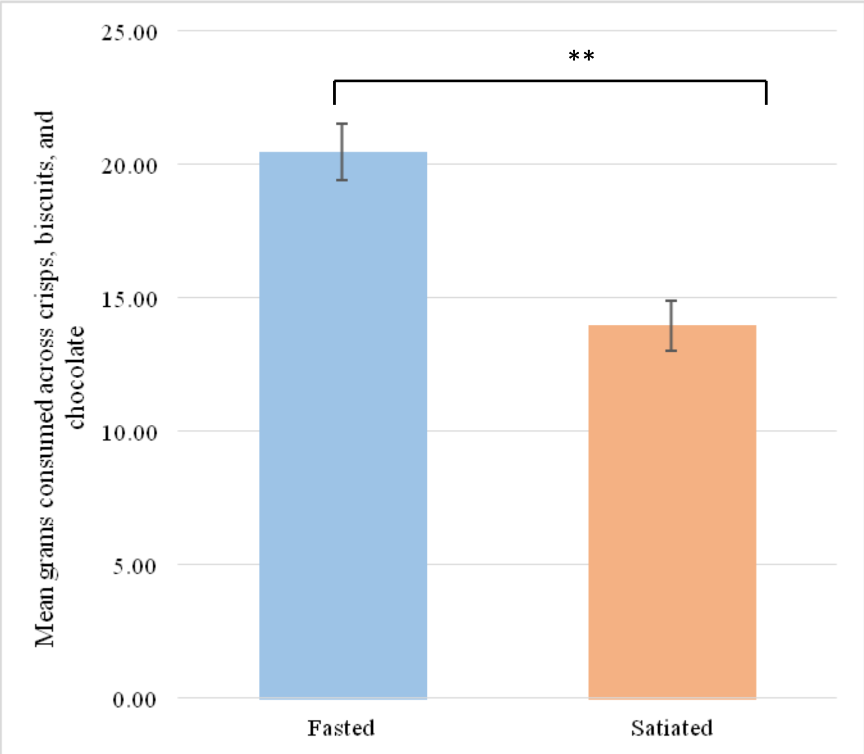


Figure 20. Mean grams eaten across crisps, biscuits, and chocolate in the fasted compared to satiated session. Error bars represent standard error.

Trait Impulsivity

A hierarchical multiple regression was carried out to examine whether PPC when fasted and trait levels of (lack of) self-control, predicted the dependent variable of total grams of food consumed during the food intake test when participants were fasted.

To examine whether these factors predict the dependent variable, total grams eaten when fasted, a hierarchical multiple regression was performed. PPC when satiated was entered in the first step to control for baseline cravings, PPC when fasted and trait levels of (lack of) self-control were then entered in the second step. The interaction term between PPC when fasted and (lack of) self-control was entered in the third step to test the moderating effect of (lack of) self-control on the relationship between PPC when fasted and total grams eaten when fasted.

It was found that adding PPC during the fasted session and trait levels of (lack of) self-control in the second step significantly increased the amount of variance explained by the model ($F(3,85)=5.80$, $p<0.001$, $R^{2\ \mathrm{adjusted}}=0.12$). However, a significant moderating effect of (lack of) self-control on PPC when fasted was not found, see Table 16.

Table 16. Multiple Regression with total grams consumed when fasted as the dependent variable and PPC when satiated, PPC when fasted, (lack of) self-control, and their interactions as independent variables.

	B	*SE B*	β
Dependent variable: Total grams consumed when fasted			
Step 1: $R = .24$, $df1 = 1$, $df2 = 87$			
Constant	42.35	5.74	
PPC when satiated	.28	.12	.25
Step 2: $R^2 = .15$, $p < 0.001$, $df1 = 2$, $df2 = 85$			
Constant	7.66	13.28	
PPC when satiated	.12	.13	.11
PPC when fasted	.30	.13	.27
(Lack of) self-control	1.72	.85	.20
Step 3: $R^2 = .17$, $p < 0.001$, $df1 = 1$, $df2 = 84$			
Constant	47.6	32.5	
PPC when satiated	.11	.13	.10
PPC when fasted	-.29	.45	-.26
(Lack of) self-control	-1.53	2.56	-.18
PPC when fasted X (lack of) self-control	.05	.04	-.66

5.4. Discussion

The current study aimed to investigate the effect of fasting on: 1) the salience of a visual food stimulus as measured through an attentional bias task, 2) the interference from food words during the Stroop task, 3) the amount that an individual is willing to work in exchange for a food item, 4) self-reported peak provoked cravings when viewing real food, and 5) the amount eaten during a bogus taste task. In addition, the moderating role of trait (lack of) self control in predicting the relationship between peak provoked cravings and amount eaten during ad libitum food intake was examined.

Saliency of Visual Food Stimulus

The saliency of food stimuli, as measured through the attentional bias task was higher in the fasted compared to the satiated session for food images. However, surprisingly the opposite was true for neutral images. There was a larger attentional bias towards neutral images in the satiated compared to fasted session. In addition there was a high degree of variance in the attentional bias scores for both the neutral and food pictures. This indicates that the attentional bias may not be a reliable measure of salience. This is in line with the findings of Ataya, Adams, Mullings, Cooper, Attwood, & Munafò, (2012), who describe variability in attentional bias studies and a lack of replicability. However, the finding of a higher attentional bias when fasted provides replicates the findings from earlier studies, Mogg, Bradley, Hyare, & Lee 1998; Nijs, Muris, Euser, & Franken, 2010; Tapper, Pothos, & Lawrence 2010; Loeber, et al., 2013; Loeber, et al., 2012).

Interference

Results from the food related Stroop task indicated a specific effect on food, but not neutral words in the fasted session. Overall, food words (low and high calorie) were associated with a greater interference effect than neutral words. Additionally, there was greater interference from food words when participants had been fasting compared to when they were satiated. However, there was no significant difference in interference scores for neutral words during the fasted compared to satiated session. This is in line with previous findings using the food Stroop that have found a specific interference effect for food words (Channon & Hayward, 1989). The findings of the systematic review (Chapter 1) also highlighted an interference effect in individuals with AN or BN, compared to HCs. This finding has been taken to indicate increased impulsivity, at least in relation to food stimuli, in individuals with an eating disorder. However, the results of the current study indicate that the state of the individual can induce this effect in healthy controls. This adds to the findings of Experiment 1 (Chapter 2), which demonstrated state impairments as a result of fasting on two measures of impulsivity previously thought to measure *trait* impulsivity. However, the degree to which the Stroop task measures impulsivity is debated (White et al., 1994), but the findings do indicate some influence of fasting on cognitive performance.

Willingness to Work Task

Participants were more willing to work for food items in the fasted compared to the satiated session. This indicates that the value of the food was higher, and participants wanted this food more when fasted, evidenced by the finding that they were willing to work harder in exchange for a food item. Overall, participants were more willing to work for food compared to neutral items, regardless of state. This is consistent with findings from the willingness to pay paradigm, which has also found higher valuation for food compared to neutral items (Plassmann, O'Doherty, & Rangel, 2007). However, this is the first study to investigate the effect of twenty hours of fasting on participant's willingness to work, rather than pay. This overcomes problems associated with the monetary value of the item influencing the participant's own valuation of the item.

Peak Provoked Cravings

Consistent with predictions, self-reported PPCs in response to viewing real food were significantly higher during the fasted compared to the satiated session, suggesting that the level of craving is increased by fasting. Additionally, participants seemed to crave biscuits more than crisps or chocolate when fasted, but there was no difference between stimulus preference when satiated. This indicates that fasting can influence the type, as well as the magnitude of craving. This is in line with previous research that has found that foods high in fat and carbohydrates are preferentially chosen after periods of food restriction (Epstein, Carr, Lin, & Fletcher, 2011).

Ad Libitum Food Intake

Again, consistent with predictions, the amount of food that participants consumed after the bogus taste test was significantly higher in the fasted compared to the satiated session. Furthermore, the quantity of biscuits consumed was higher compared to the quantity of crisps or chocolate. This could be a reflection of the PPCs and the higher cravings towards biscuits. The larger quantity of food consumed after fasting provides evidence that the fasting manipulation was successful.

Peak Provoked Cravings, Impulsivity, and Ad Libitum Food Intake

The model regressing PPCs when fasted and (lack of) self-control onto fasted ad libitum food intake when controlling for satiated PPCs was found to be significant. PPCs when fasted and (lack of) self-control separately explained a significant proportion of variance in the amount of food eaten when fasted. However, there was no moderating effect of (lack of) self-control on the relationship between fasted PPCs and fasted food intake, see Fig 21, *(a)*, for the hypothesised model. This is in contrast to previous research that suggests a moderating role of impulsivity on this relationship (Jansen et al., 2009; Meule, Lukito, Vogele, & Kubler, 2011). In contrast to previous literature the current study provides evidence to suggest that fasted PPCs and (lack of) self-control independently predict amount eaten when fasted, see Fig 21, *(b)*.

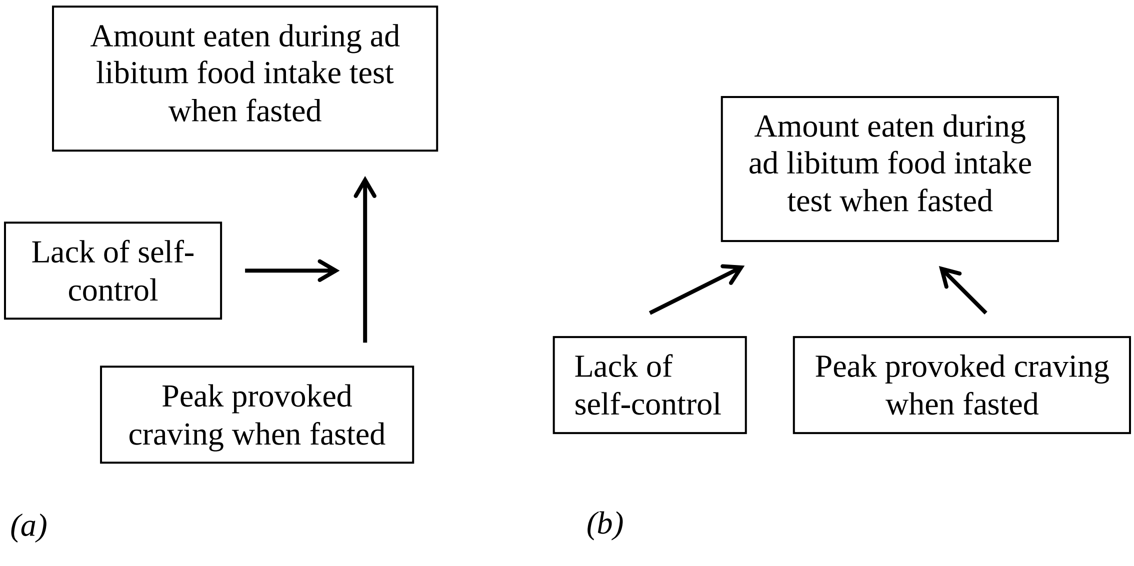


Figure 21. *(a)* The hypothesised moderating role of (lack of) self-control on peak provoked cravings when fasted in predicting the dependent variable, amount eaten during ad libitum food intake test when fasted. *(b)* The supported model of the independent variables, (lack of) self-control and peak provoked cravings when fasted independently predicting the amount eaten when fasted.

Limitations

The interpretation and generalisability of the current findings is limited by a number of factors. Firstly, the study was only conducted in healthy, female controls. This limits the applicability of the findings to those with disordered eating, but could provide insight into the risk factors that could be implicated in the development of disordered eating in the general population. Additionally, the recruitment of only female healthy controls was intentionally designed so as to allow comparisons to previous literature and to control for differences amongst gender in self-reported cravings (Cepeda-Benito, Fernandez, & Moreno, 2003). Secondly, although the ad libitum food intake test was used as an approximation of 'real world' eating behaviour, such as bingeing, it is likely that food intake in the laboratory and the 'real world' differs. Participants may have guessed the purpose of the bogus taste task and regulated their behaviour in accordance with expectations/social desirability. However, the fact that there was a significant relationship between PPCs and amount eaten provides some support for the validity of this task. Thirdly, although the attentional bias task was developed and successfully piloted, the degree to which this task reliably measures attentional bias is questioned (Ataya et al., 2012). There was a high degree of variance in the attentional bias scores, and a more direct measure of attentional deployment, such as tracking of eye gaze may provide a more accurate measure of salience in future studies. Finally, the degree to which the increased cravings as a result of fasting could account for the disruptions in cognitive performance between fasted and satiated sessions in previous experiments cannot be fully concluded. The current study established that food stimuli, in comparison to neutral stimuli led to increased cravings and increased interference in performance. However, as the current study did not include a measure of cognitive performance that has previously been demonstrated to be affected by fasting, the degree to which increased cravings relate to general cognitive impairments when fasting cannot be determined.

Future Directions

The current findings would benefit from being extended to investigate how the increased cravings established in this study could account for impairments in cognitive performance previously found, such as the decreased action inhibition seen in Experiment 1 (Chapter 2). Results from the current study indicate that the increased commission errors seen in Experiment 1 could be due to increased interference from the food stimuli used. Fasting could have influenced the processing towards food stimuli, causing impairment on the task.

Although the current study was not conducted in individuals with an eating disorder, the results could provide some insight into the development of disordered eating in the general population. The current CB model of BN states that strict dieting leads to binge eating. Fairburn outlines three types of dieting that occur in BN including; 1) Avoiding eating – eating nothing at all in between binges, such as fasting for days at a time, 2) Restricting overall amount eaten – keeping calorie intake below a certain amount per day, and 3) Avoiding certain types of food – not eating ‘forbidden’ or ‘bad’ foods (Fairburn 1995).

The current results suggest that the first type of dieting (avoiding eating) even in the absence of concerns about shape and weight, can at times lead to increased food consumption. However, this increased consumption is predicted by both trait impulsivity and increased cravings. Trait impulsivity, when combined with fasting behaviour could then be viewed as a risk factor for the development of disordered eating. This is an important finding as recent extreme weight loss plans termed ‘intermittent fasting diets’ that involve alternating between 2 days of minimal intake (3-500 calories) and 5 days of normal eating have become increasingly popular. This cyclical pattern of fasting within the diet is similar to that seen in individuals with BN, and this type of fasting could act as a precursor to the development of an eating disorder in vulnerable individuals. Although some research has shown that dietary restraint commonly leads to episodes of extreme overeating or bingeing (Greeno et al., 2000), and that this relationship is mediated by cravings (Engelberg et al., 2005), little research has investigated the moderating role of impulsivity. The current results suggest that the role of trait impulsivity as a risk factor should be further investigated. Firstly, the relationship between trait impulsivity, bingeing and fasting should be further clarified. Although the self-report measure of (lack of) self-control was chosen due to its use in previous studies, the degree to which self-reported impulsivity and behavioural measures of impulsivity correlate is debated (White et al., 1994). A thorough and systematic investigation of the components of impulsivity should be investigated in relation to fasting and subsequent bingeing. Once established, this could then be examined naturalistically in clinical samples in order to capture real binge behaviour, as opposed to laboratory measures of food intake.

Summary

The current study demonstrated that short-term fasting increased the rewarding nature (value) of a food stimulus, self-reported cravings, amount eaten, the interference from, and saliency of food stimuli. Additionally, peak provoked cravings and a (lack of) self-control independently predicted amount eaten when fasted. The results indicate that the impaired cognitive performance as a result of fasting found in previous experiments could be due to interference from the increased cravings or salience of food. In addition the results suggest that the role of trait impulsivity should be considered as a potential risk factor for the development of binge eating, and should be investigated further.

6. Chapter Six: General discussion

Central to this PhD thesis was an examination of the influence of short-term fasting on cognitive performance. The presence of short-term fasting is a confounding factor in existing research investigating cognitive performance in individuals with an eating disorder. The development of novel therapies targeted towards the cognitive impairments in eating disorders are based on this research. Therefore, the possible role of short-term fasting on these measures needs to be investigated.

6.1 Aims of the thesis

This thesis aimed to address the following questions:

1. Can short-term fasting influence performance on cognitive measures of impulsivity?
2. Can short-term fasting influence performance on cognitive measures of compulsivity?
3. If so, to what degree can self-reported hunger account for any impairment in cognitive performance on these measures of impulsivity and compulsivity?
4. What possible mechanisms could account for any effects of fasting? In particular, is any observed effect of fasting related to cravings induced through food deprivation?

In this chapter I will discuss the ways in which the results of the experiments included in this thesis are able to answer the above questions. Additionally, the theoretical and clinical relevance of these findings will be discussed, along with methodological limitations and suggestions for future research.

6.2. Summary of findings

Chapter one aimed to systematically appraise cross-sectional research that compared the cognitive performance of individuals in the acute phase of BN and/or AN, to HCs on measures of impulsivity and compulsivity. The results of the systematic review showed support for the trans-diagnostic approach to eating disorders. There was no strong evidence to support the characterisation of AN as high in compulsivity (and low in impulsivity), nor to support the characterisation of BN as high in impulsivity (and low in compulsivity). There appeared to be mixed findings for both impulsivity and compulsivity across AN and BN. Results were highly variable due to the heterogeneous tasks used, and lack of replication across studies. There was no consensus amongst the included studies on the most appropriate task and/or outcome measures that should be used to study the constructs of impulsivity and compulsivity. There appeared to be little consideration of how the co-morbidities associated with having an eating disorder may influence task performance. Similarly, the extent to which the symptoms of the eating disorder itself, such as starvation, may affect the findings was not taken into account. This is an important factor as starvation, and short-term fasting have both been shown to influence behaviour and cognitive performace, (Keys, 1950; Benau, Orloff, Janke, Serpell, & Timko, 2014; Bolton, Burgess, Gilbert, & Serpell, 2014; Pender, Gilbert, & Serpell, 2014; Symmonds, et al., 2010; Levy, Thavikulwat, & Glimcher 2013).

Therefore Chapter 2 aimed to overcome some of these limitations and to investigate the role of fasting on measures of impulsivity in a healthy population. Experiment 1 was designed to assess the effect of fasting on four separable components of impulsivity in isolation from the complex influences of eating disorder psychopathology. The results of Experiment 1 showed selective effects of fasting on tasks measuring specific facets of impulsivity. When fasted, individuals made more errors of action inhibition compared to when satiated - that is they became more impulsive. However, the opposite was true for the measure of reflection impulsivity. Participants opened more boxes in the FW condition of the IST when fasted. There was no effect of fasting on measures of delay aversion, or on a risky-decision making task. The results of the experiment showed that manipulations of the physiological state of the individual (fasted vs. satiated) could influence performance on measures of impulsivity, previously thought to measure trait characteristics. The finding of increased reflection impulsivity as a result of fasting was in an unexpected direction, and warranted further investigation. The increased box opening could have been accounted for by an increase in compulsive responding, such as difficulties in set-shifting. Experiment 2 was therefore designed to investigate this effect further and distinguish between a number of possible explanations for the specific finding of increased reflection impulsivity when fasting.

The results of Experiment 2 showed no effect of fasting on measures of set-shifting or central coherence. Additionally, the finding of increased box opening in the FW condition of the IST from Experiment 1 was not replicated. A number of possible explanations for the differences in findings between Experiments 1 and 2 were considered. It seems likely that the effect of fasting on cognitive performance is variable. For example, there were differences in the self-reported hunger between Experiment 1 and 2. Self-reported hunger was higher in Experiment 1, however this was not correlated to blood glucose. Based on previous findings in the literature linking increased hunger and impaired cognitive performance Experiments 3a and b were designed to look at the naturalistic correlation between self-reported hunger and measures of impulsivity and compulsivity. These studies aimed to determine whether the difference between Experiments 1 and 2 for self-reported hunger could account for the lack of replication.

Experiment 3b showed a significant correlation between the number of boxes opened during the FW condition of the IST and self reported hunger, but no other measures of impulsivity or compulsivity were found to be correlated with hunger. This finding could provide support for the view that lower hunger ratings in Experiment 2 accounting for the lack of replication. This would suggest that it is hunger, rather than fasted state per se, that is required for the specific pattern of findings in the IST. However, it is hard to draw firm conclusions on the basis of these results due to the correlational nature of the study.

Experiment 4 was designed to examine whether the effect of fasting was related to food deprivation and whether this could be exacerbated by cognitive tasks that use food stimuli as cues. In addition, it aimed to explore to whether the effects of fasting are due to increased cravings impairing cognition, as a result of exposure to food cues. Furthermore, the study aimed to examine the moderating role of (self-reported) trait impulsivity on ‘real world’ behaviour; the amount eaten during a food intake test.

Results showed that the saliency of food, interference from food, cravings towards food, and the value of food were all higher when participants had fasted. Both trait impulsivity (lack of self-control) and cravings towards food independently predicted the amount participants ate when fasted. However, the model that tested a moderating effect of impulsivity on cravings predicting amount eaten was not supported.

In summary, the research in this thesis shows that short-term fasting can influence cognitive measures thought to represent trait characteristics. Specifically, when fasted, participants showed lower action inhibition compared to when satiated, a facet of impulsivity. The results for reflection impulsivity were more variable and preliminary evidence suggests that this could be related to variation in hunger. Furthermore, fasting is associated with increased cravings towards food cues and together with trait impulsivity was able to predict the amount that participants consumed when fasted.

Research in this thesis highlights that the role of short-term fasting should be considered and further investigated in individuals with EDs. Whilst there is no evidence to suggest that all cognitive differences between those with EDs and HCs are due to differences in fasting status, the findings do suggest some impact for particular cognitive tasks. The results should be considered when interpreting evidence from cross-sectional studies comparing HCs to individuals with an ED who may differ in terms of short-term fasting or chronic starvation. Additionally, the degree to which increased trait impulsivity, and cravings as a result of fasting, could act as a risk factor for the development of disordered eating in the general population should be further investigated. This is especially important due to the recent increase in the popularity of intermittent fasting diets following widespread coverage in the media. Individuals following such diets severely restrict their food intake on two out of seven days (Mosely & Spencer, 2013). It is possible that certain individuals, such as those with high trait impulsivity, may be at risk of developing disordered eating in response to fasting. If the findings of Experiment 4 are confirmed in further research, this may suggest that such individuals should avoid intermittent fasting diets and instead follow a programme of modest caloric restriction combined with increased exercise.

Thesis aims:

The thesis aimed to answer the following questions:

1. What is the evidence that short-term fasting influences performance on cognitive measures of impulsivity?

Previous research examining the effect of fasting on risky decision-making has shown that participants make more risky decisions in gambling simulations when in a fasted compared to a satiated state (Symmonds et al., 2010; Levy et al., 2013). However, the results of Experiment 1 did not support this finding. Experiment 1 did not find any effect of fasting on a measure of risky decision-making. Levy and colleagues (2013) measured the risk attitudes towards the primary reinforces food and water, and the secondary reinforcer money. This is in contrast to the current study, which used points. It is likely that points, compared to food, water, or money may not be as rewarding or related to the motivational state of the individual. Furthermore, in contrast to Symmonds and colleagues (2010), who used only males, the current study was conducted in females. Together the differences between experiments could have accounted for the lack of replication. It is likely that risk attitudes towards points are not influenced by the state of the individual, but represent a more stable trait. However, the extent to which risk attitudes towards rewards related to the motivational state of the individual is still debatable. For example Experiment 4 suggests that the use of food cues can lead to increased valuation, and salience of food items. Therefore utilising food rewards, as opposed to points may cause a change in risk preferences across fasted and satiated sessions.

Results from Experiment 1 also showed that delay aversion was not influenced by the effect of fasting. The choices that participants made across sessions did not vary as a function of manipulations to the physiological state of the individual. Although the effect of fasting in the general population on delay aversion has not been investigated the current results seem to support prior research suggesting that delay aversion is a stable trait characteristic, not influenced by motivational state, (Mitchell, 1999; Odum, 2011; Kirby, 2009). Additionally, there were a higher number of errors of commission made by participants in the fasted compared to satiated condition. This was specific to food, and most pronounced in the more difficult shifting condition of the AST. Higher errors of commission in individuals with BN have previously been interpreted as evidence for decreased action inhibition, suggesting increased impulsivity (Rosval, Steiger, Bruce, Israël, Richardson, & Aubut, 2006). This indicates that there are selective effects of fasting on dissociable components of impulsivity, and could explain the inconsistencies in the ED literature on impulsivity described in Chapter 1. Furthermore, the results showed that fasting appeared to be related to a decrease in reflection impulsivity, as measured by the IST. Participants opened more boxes during the FW condition when fasted. This finding was unexpected, and not replicated during

Experiment 2. Together this suggests that the effect of fasting can be variable, and the processes responsible for impaired cognitive performance are not fully understood. However, this is the first study to systematically isolate and examine the effect of fasting on separable constructs of impulsivity. The results show differential effects of fasting on the separable components of impulsivity. These findings should be taken into consideration when interpreting results from cross sectional research using these measures in the eating disorders field.

2. What is the evidence that short-term fasting influences performance on cognitive measures of compulsivity?

Experiment 2 failed to find any evidence that measures of compulsivity and central coherence were affected by fasting. This suggests that measures of compulsivity are not influenced to the same degree by changes to the physiological state of the individual as measures of impulsivity. However, this finding is in contrast to previous research using the same tasks, with a similar period of fasting (Bolton et al, 2014; Pender et al 2014). Differences in the sample sizes between the current and previous research could have accounted for this difference. The sample size of Experiment 2 was determined by a power calculation conducted a priori. The experiment was sufficiently powered to detect a medium effect size. However, although the power calculation performed in the study by Pender and colleagues (2014) indicated a required sample size of 34, a total of 60 participants were included. However, this explanation cannot account for the lack of replication of the IST in Experiment 2, as a similar sample size was used across Experiments 1 and 2. Alternative explanations related to blood glucose and self-reported hunger were considered. Exploratory analysis comparing Experiments 1 and 2 highlighted significant differences in the blood glucose and self-reported hunger. Participants in Experiment 2 had higher blood glucose levels and reported feeling less hungry compared to Experiment 1. It is possible that in Experiment 2, the participants did not reach a sufficiently low blood glucose level in order to observe task impairments (Blackman et al., 1990). Therefore it is difficult to fully conclude that fasting does not impair compulsivity. Rather, it is more likely that the effects of fasting are variable and that the processes that contribute to impaired performance are not yet fully understood.

3. What is the evidence that self-reported hunger accounts for the impairments in cognitive performance on measures of impulsivity and compulsivity?

In order to investigate whether naturalistic hunger could be separable from the effect of enforced fasting and the resulting lowered blood glucose, a cross sectional study looking at the relationship between hunger and measures of impulsivity and compulsivity was run. There was no observed relationship between any of the measures of impulsivity or compulsivity with hunger, except for the number of boxes opened during the FW condition of the IST. A limitation of Experiment 2 was the inability to compare performance on the measures of set-shifting used, as these have not previously been used in the eating disorders literature. Therefore Experiment 3a used measures of set-shifting used in previous studies of eating disorders, such as the WCST and the TMT, to allow for comparisons with this literature. However, this then limited comparisons with the other experiments conducted in this thesis, although the study indicates that hunger is not related to measures of compulsivity. The finding of increased box opening with increased hunger only in the FW condition of the IST, is similar to the results found during Experiment 1. It is interesting to note that this effect could be related to hunger levels, as this could explain the lack of replication in Experiment 2 where there participants showed lower overall hunger. However, the conclusions that can be drawn from this study are somewhat limited due to the methodology. Firstly, the study was correlational and so direction of causation could not be determined. Secondly, the naturalistic nature of the study meant that participants are likely to have eaten once they were moderately hunger, rather than restricting their intake, hence the study may not have sufficiently measured the full variance of hunger that could be experienced.

4. What possible mechanisms could account for any effects of fasting? In particular, is any observed effect of fasting related to cravings induced through food deprivation?

The final study included in this thesis aimed to answer the question of whether the effect of fasting could be related to the type of stimulus used. Specifically, it aimed to determine whether manipulating the physiological state of the individual could lead to task impairments due to the increased motivational salience related to the food stimuli used. In addition the experiment was designed to examine whether any increased cravings as a result of fasting could be moderated by trait impulsivity to predict real world behaviour, amount eaten during an ad libitum food intake test. The results of this experiment showed clear results.

Firstly, the salience of visual food cues was higher when fasted, and this attentional bias was not present for neutral items. Secondly, interference from food words, but not neutral words was present during a fasted compared to satiated session. Thirdly, the motivational value that participants assigned to food items was higher when fasted, but this effect was not present for household items. Finally, the presence of food items when fasted caused increased cravings towards those items, and increased consumption of those food items. The degree to which an individual craves food, and trait levels of (lack of) self-control independently predicted the amount eaten when fasted. Together these findings suggest that some cognitive task impairments as a result of fasting could be related to the interference arising from the food cues used in the study, such as the AST used in Experiment 1. As the physiological state of the individual is manipulated, the motivational properties of the food cues appear to change and begin to interfere with task performance.

These findings are in line with previous research that has demonstrated an effect of food deprivation on cognitive performance but is the first study to combine these measures into the same experiment (Mogg, et al., 1998; Nijs, et al., 2010; Tapper, et al., 2010; Loeber, et al., 2013; Loeber, et al., 2012. This then allowed for an examination of whether these processes, together with trait impulsivity, could account for variability in food intake. The model of a moderating effect of trait impulsivity on the relationship between craving and amount eating was not supported. However results suggested that trait (lack of) self-control and cravings independently predicted amount eaten.

6.3. Limitations

A limitation of the experiments included in this thesis is the sample population studied. All experiments used females, in order to facilitate comparisons with previous literature and to rule out gender differences. However, this limits generalisability, and is problematic especially when the rate of males diagnosed with an ED is on the rise (Micali, Hagberg, & Peterson et al., 2013). Furthermore, there may have been a self-selection bias in the participants that signed up to the fasting experiments. Advertising materials clearly stated that participants would be required to fast. Fasting for twenty hours is likely to be an adverse experience, and the decision to participate may reflect some inherent bias in the traits of those individuals, such as previous positive experiences of fasting, or finding fasting relatively easy. Therefore the characteristics of the study sample may not be representative of the general population.

The aim of the thesis was to investigate the role of fasting on neurocognitive performance, without the confounding factors of eating disorder psychopathology. The advantages of this are clear, however, it is acknowledged that this decision means that the findings cannot directly be applied to the field of eating disorders, and this limits the applicability of the research.

The results of these studies demonstrate that caution should be taken when interpreting findings from studies comparing individuals with EDs to HCs using stimuli relevant to the motivational state of the individual. However, it is not known whether individuals with an eating disorder differ in their response to fasting. Fasting could exacerbate difficulties in an additive manner, or alternatively have little effect due to the regularity or chronicity of the practice. The body is able to regulate itself through homeostatic mechanisms and it is conceivable that individuals with an ED who engage in regular fasting may not experience the same cognitive impairments as those observed as a result of singular episode of fasting in the general population. Furthermore the impact of fasting on the variables studied, blood glucose and hunger, could be influenced by other factors not measured in this thesis. Factors such as the amount of exercise an individual completes and/or past or current medication could influence metabolism and impact the outcome variables of blood glucose levels or hunger. It is likely that there could be genetic influences on individual responses to fasting that could have also influenced outcome measures.

Given the findings regarding self-reported fasting in experiments 3a and 3b, it is important to note that people with an eating disorder may have abnormal perceptions of hunger and satiety (Uher, Treasure, & Cambell, 2002). Individuals with AN have been shown to report a lack of hunger, whereas those with BN report increased hunger, even after a large meal, (Owen, 1985; Halmi, 1988; Halmi & Sunday, 1991; Hetherington & Rolls, 1991, 2001). Therefore, findings of clinical studies asking participants to self-report hunger may be different from the current studies. Furthermore, it may not be feasible, or reliable to ask participants with eating disorders to self-report hunger levels.

However, the purpose of the research set out in this thesis was not to provide evidence directly transferable to eating disorders but rather to demonstrate a proof of concept. The studies show that short-term fasting, even in the absence of eating disorder psychopathology, can, under certain conditions, cause specific impairments on tasks measuring 'trait' characteristics. This demonstrates the importance of considering the physiological state of individuals completing the research and ensuring that groups are matched on variables relating to starvation past BMI. Further research is needed to determine the best way to account for any differences between HCs and ED populations. This is crucial in order to fully understand the traits present in EDs and whether these traits are a consequence or a cause of the disorder. The research conducted in this thesis is a preliminary start to understanding the role of short-term fasting on cognition, and further studies examining the exact mechanisms and markers, such as hormones, that can reliably indicate levels of short-term fasting should be conducted.

6.4. Future Directions

The research included in this thesis provides preliminary findings, which could be extended in two main ways. Firstly, the findings of Experiment 4 suggest a role for increased cravings and impulsivity in explaining overeating as a result of fasting. The results demonstrated a link between increased cravings as a results of fasting, and higher levels of (lack of) self-control predicting amount eaten during the food intake taste. Further research is needed to determine whether impulsivity, and more specifically which type of impulsivity, could act as a risk factor for the development of binge eating in individuals with concerns about weight/shape. The current results show a link between fasting and overeating, in partial support of the CB model of BN (Fairburn, 1995). However, the results suggest that this overeating is predicted by the cravings induced through fasting. This adds to our understanding of the intermediate processes involved in the links between fasting, and bingeing, as suggested by Fairburn's CB model (1995), and can help to explain why not all individuals binge following fasting, as well as why individuals with BN do not inevitably binge following fasting.

Therefore the role of impulsivity as a possible risk factor for the development of bingeing in addition to fasting should be further investigated. The role of fasting, cravings and impulsivity should be investigated as possible risk factors for the development of disordered eating in those with concerns about weight and/or shape. An approach to this would be to longitudinally examine individuals who start fasting diets, such as the popular 5:2 diet. A full range of impulsivity tasks and self-report measures could be completed prior to the start of the diet, in addition to measures of eating disorder psychopathology. Participants could then be intermittently assessed, and tracked for evidence of the development of disordered eating such as bingeing, or disordered thoughts about eating, shape and/or weight. The relationship between the individual's personality characteristics such as impulsivity and the possible interaction with fasting could then be used to predict who is at risk for the development of disordered eating. Early findings in our lab suggest that most individuals commencing intermittent fasting diets do *not* develop disordered eating (Langdon-Daly, personal communication, 23/9/15). Hence it will be important to use the findings of this thesis to attempt to predict individuals who may be high risk.

A second line of research that could build on the results of this thesis is the investigation of whether there are differences between fasted HCs and individuals with an eating disorder on the measures of impulsivity which have been shown to be influenced by fasting. Conducting cross sectional research examining individuals with an ED, to HCs when fasted and satiated could help explain inconsistencies in the previous ED literature. If there was no difference in the impulsive performance between ED groups and fasted HCs this may confirm the importance of considering short-term fasting in ED research. Furthermore the reliability of the fasting paradigm, and more appropriate markers of fasting should be identified, such as hormones. Relying on self-reports from participants, and blood glucose, a secondary marker of fasting may not be reliable.

Future research should explore whether the findings of the current thesis are replicable in clinical populations. It is not ethically acceptable to ask eating disordered patients to fast; however it would be possible to naturalistically explore the degree of fasting and relate this to cognitive performance. One approach to this could involve recruiting participants from different types of eating disorder services and from support groups such as those run by agencies such as B-EAT. Recruiting from inpatient services where patients are likely to be receiving regular nutrition, and also from outpatient services or the voluntary sector where patients may be restricting for long periods would allow considerable variation in the degree of fasting. Acute and chronic fasting could be estimated using variables such as time since last ate and recent caloric intake.

6.5. Summary

In conclusion the research in this thesis demonstrates proof of concept that the physiological state of the individual, manipulated through fasting, has effects on constructs of impulsivity and the way in which food cues are processed. The results indicate the importance of the stimuli used in paradigms manipulating food deprivation/fasting and consideration of the traits of the individual. This is the first study to demonstrate the influence of fasting on cravings and subsequent food intake in consideration of the trait characteristic of impulsivity. Furthermore, the systematic review of the literature highlights the need for consensus amongst researchers in the ED field regarding the most appropriate tasks used to measure the constructs of impulsivity and compulsivity. There then needs to be a consistent approach adopted, so that comparisons between research studies can be made. Additionally, the role of short-term fasting has been demonstrated to be important and should not be overlooked when conducting research in EDs and in intermittent fasting. The exact mechanisms that are related to cognitive impairments as a result of fasting should be further researched and tested in the ED population.

7. References

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8. Appendices

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

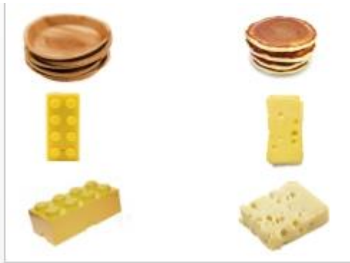
Section/Topic	**Item #**	**Recommendation**	**Reported on page #**
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	
Objectives	3	State specific objectives, including any prespecified hypotheses	
Methods			
Study design	4	Present key elements of study design early in the paper	
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	

Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	
Bias	9	Describe any efforts to address potential sources of bias	
Study size	10	Explain how the study size was arrived at	
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	

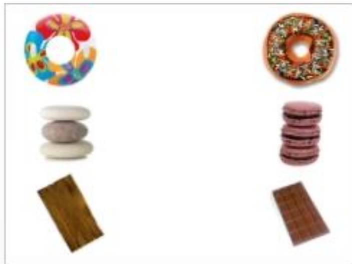
*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

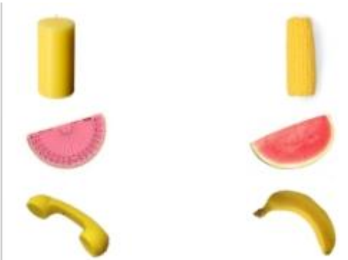











UCL RESEARCH ETHICS COMMITTEE

Amendment Approval Request Form

1	**ID Number:** 2337/001	**Name and Address of Principal Investigator:** Dr Lucy Serpell, Dept of Clinical Health Psychology, 4th Floor, Torrington Place, London, WC1E 6BT
2	**Project Title: The Impact of Fasting on Concentration**	
3	**Information about the amendment:** (a) Is the amendment purely administrative? ☐ Yes ☑ No ☐ N/A (b) Has the Participant Information Sheet/Consent Form been changed as a result of the amendment? If yes, please enclose a copy. ☑ Yes ☐ No ☐ N/A	

4

Summarise the issues contained in the amendment:

The experimental design of the research remains the same, however some of the measures will be substituted. Four behavioural tasks measuring levels of impulsivity will be employed replacing the existing computer tasks. In addition a questionnaire measure of impulsivity, the UPPS Impulsive Behaviour Scale will be given.

Whiteside, S. P., & Lynam, D. R. (2001). The five factor model and impulsivity: using a structural model of personality to understand impulsivity. *Personality and individual differences, 30, 669-689*

The Information Sampling Task is designed to give a measure of reflection impulsivity: the tendency to evaluate information before decision-making. In this task participants are presented with a 5 by 5 matrix of grey boxes. There are two large coloured panels at the foot of the screen. Touching the grey box causes the box to open revealing one of the two colours The aim of the task is to decide the box colour in the majority. Once opened boxes remain open, and subjects can open as many boxes as they want before making their decision. Hovering the mouse over the coloured panel reveals the boxes in the majority and allocates points for correct judgements and minus points for incorrect judgements. There are 2 different trials within the task. The FW condition means that the subject can win or lose 100 points on each trial irrespective of the number of boxes opened. In the DW condition, the available win decreases from 250 points in 10-point steps with every box opened. Performance is calculated by the average number of boxes opened and the number of incorrect judgements made in each condition. Motivation is the latency of box opening (number of boxes opened divided by time to make a decision).

The second task is the Go-No-Go task used to measure motor impulsivity. Participants are asked to respond to stimuli (household objects) on the screen by pressing the space bar. They are told that when they see a specific type of stimuli (in this case, food items) they should inhibit their response and not press the space bar. Half way through the task the rules are reversed so participants should then respond to food items and not to household objects. Both latency of response and errors are recorded for analysis.

The third task has been designed to take a measure of risky decision-making. In this task participants are asked to make a choice between two 'gambles'. These gambles are presented visually as a histogram displaying the probability of gaining a certain number of points. In each trial there is always a 'control gamble' which has its probability set at 50% to lose 10 points and 50% to gain 10 points. The other 'experimental gamble' can vary in the probabilities of winning and losing to be high or low (75% vs. 25%) the expected gains either large or small (80 vs. 20 points) and the expected losses, large or small (80 vs. 20 points). The 'experimental' and 'control gambles' are presented randomly on either the left or the right of the screen and the participant is required to indicate (using a key press response) their choice of gamble. The number of choices for the 'experimental gamble' over 'control' as a function of the probability, the size of expected gains, and the size of expected losses in the 'experimental gamble' gives an indication of the participants impulsivity in the context of decision making.

The final task asks participants to choose between two serially presented options of differing magnitude (from £1 to £100) and delay (from 1 week to 1 year). Participants are told that one of the choices that they have made during the experiment will be selected and paid for in real money from a prepaid credit card that has a timed activation date. This task is a measure of temporal discounting: the degree to which the participant views the future reward as less valuable than current rewards and gives an indication of impulsivity, where more impulsive individuals will place higher value to immediate rewards.

Further to this levels of blood sugar level will be taken by employing the use of a glucose meter. This device obtains a small drop of blood by pricking the skin with a lancet. This drop of blood is then placed on a test strip and inserted into a meter that calculates the blood glucose level. This measure will then be used to validate whether or not the participant has fasted and will also be used to investigate the relationship between glucose levels and task performance.

5 Please give any other information you feel may be necessary:

Signature of Principal Investigator: **Date of Submission:** 9/11/11.

FOR OFFICE USE ONLY:

Amendments to the proposed protocol have been .... by the Research Ethics Committee.

Chair's Signature: Date:

Please return completed form to:

Secretary of the UCL Research Ethics Committee
Graduate School, North Cloisters, Wilkins Building
Gower Street, London WC1E 6BT

ethics@ucl Helen Dougle

The Impact of Fasting on Concentration

This study has been approved by the UCL Research Ethics Committee [2337/001]:

Maxine Howard and Dr Lucy Serpell c/o Dept of Clinical Health Psychology, 4th Floor, Torrington Place, London, WC1E 6BT

You are being invited to participate in this research project.

You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Details of the Study

The study explores the relationship between blood sugar levels and measures of concentration. The aim of the study is to understand if these measures are related to one another, and to find out what effect short-term starvation has on people's performance on tasks related to concentration.

We are recruiting healthy female volunteers aged between 18 and 30.

If you agree to take part in the study we will meet with you at UCL or a place of your choosing on two separate occasions, about a week apart. Each testing session will last about an hour. At each session, we will ask you to complete some questionnaires, some computer tasks, and to take a measure of blood sugar levels by gently pricking the finger.

Before one session we will ask you to fast for about 20 hours beforehand. There is more information on fasting below. We will also ask you to fill in a diary about your mood, how much you are thinking about food, and how hungry you are while fasting.

You can receive either 3 course credits or £22.5 (£7.50 per hour) for your participation in this study. We will update the SONA records at the end of the second testing session.

It is unlikely that you will experience any distress by taking part in this study, although you may wish to consider the potential effects that fasting might have on you in the short term before agreeing to participate.

It is up to you to decide whether or not to take part. If you decide to take part you are still free to withdraw from the study at any time during the testing session and without giving a reason. This will not affect your rights in any way.

If you decide to take part in the study you will be given this information sheet to keep and we will ask you to sign a consent form. As participation is anonymous it will not be possible for us to withdraw your data once you have completed the study. No information about you will be disclosed to a third party.

For more information and to sign up to this study please see: http://uclpsychology.sona-systems.com/exp_info.asp?experiment_id=3134

Or contact: maxine.howard.11@ucl.ac.uk Phone: 07545481971

All data will be collected and stored in accordance with the Data Protection Act 1998.

Informed Consent Form for Participants in Research Studies

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Project: The Impact of Fasting on Concentration

This study has been approved by the UCL Research Ethics Committee [Project ID Number:]

Thank you for your interest in taking part in this research. Before you agree to take part the person organising the research must explain the project to you.

I ________________ confirm that I have read the Information Sheet for Participants, and that I have had an opportunity to ask the researcher any questions or raise any concerns about the project with her, and have had these answered satisfactorily. ☐

I understand what taking part in the study involves. ☐

I understand that participation is voluntary, and I am free to withdraw from the study at any time during the testing sessions, without giving a reason. ☐

I have read the information sheet about the effects of fasting and I understand that I am free to stop fasting at any point should I feel unwell or uncomfortable. I confirm that I will follow the guidelines for fasting and should I feel faint or sick while fasting I will eat something. ☐

Signed: Date:

UCL RESEARCH ETHICS COMMITTEE

Amendment Approval Request Form

1	**ID Number:** ~~2337/001~~ 3529/001	**Name and Address of Principal Investigator:** Dr Lucy Serpell, Dept of Clinical Health Psychology, 4th Floor, Torrington Place, London, WC1E 6BT
2	**Project Title:** ~~The Impact of Fasting on Concentration~~ Predicting individual responses to fasting.	
3	**Information about the amendment:** (a) Is the amendment purely administrative? ☐ Yes ☑ No ☐ N/A (b) Has the Participant Information Sheet/Consent Form been changed as a result of the amendment? If yes, please enclose a copy. ☐ Yes ☑ No ☐ N/A	
4	**Summarise the issues contained in the amendment:**	

The main experimental design of the research remains the same. However, some of the measures will be substituted. Four computer tasks will be employed replacing three of the existing computer tasks. One of the existing tasks (The Information Sampling Task) will be a slightly modified version, and details can be found below. In addition questionnaire measures of persistence and perseveration, obsessive compulsive traits and an additional measure of impulsivity will be given. These questionnaires are:

Perfectionism, Persistence and Perseveration Questionnaire (PPPQ): Serpell, L, Waller, G., Fearon, P. & Meyer, C. (2005). Understanding perseverance, persistence and perfectionism

Obsessive Compulsive Inventory (Foa, Kozak, Salkovskis, Coles & Amir 1998) - a self report scale to assess levels of obsessive compulsive symptomatology.

BIS/BAS. 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 and Social Psychology, 67, 319-333.

Computerised Tasks

The Alphabet Task is designed to give a measure of the degree of difficulty that a participant experiences when shifting between responding to a stimulus presented on a screen and when responding to a mentally represented stimulus.
The participants are asked to press one of three buttons to indicate whether capital letters, presented on the screen are made up of straight lines, curved lines, or a mixture of both (external phase). Immediately after each button press, another letter is presented for classification in the order of the alphabet, but skipping two letters at a time. Then participants are instructed to continue looking at the screen (where instead of letters, question marks are presented either upside down or not) and asked to mentally continue classifying the letters of the alphabet in the

Predicting Individual Responses to Fasting

This study has been approved by the UCL Research Ethics Committee [Project ID Number]:

Dr Lucy Serpell
Department of Clinical, Educational and Health Psychology,
4th Floor, Torrington Place, London, WC1E 6BT

You are being invited to participate in this research project.
You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Details of the Study

What is the study about?
This study explores different individual's responses to fasting. The aim of this study is to understand what effect short-term fasting has on people's performance on tasks relating to concentration, and how this might be different for people with different personality characteristics.

What will I have to do?
This study consists of two components:

<u>Component 1</u>
If you agree to take part in the study you will be invited to come to UCL for an initial session lasting ninety minutes. During this session you will be asked to fill in some questionnaires, and complete some computer tasks. The computer tasks involve rating neutral images, matching perceptual shapes and responding to different rule changes.
After the initial session you may be invited back to participate in Component 2. You do not have to participate in Component 2 after participating in Component 1.

<u>Component 2</u>
Component 2 consists of two sessions (spaced seven days apart) lasting for ninety minutes each. At each session, we will ask you to complete some questionnaires, some computer tasks, and to take a measure of blood sugar by gently pricking the finger.
Before one session we will ask you to fast for 20 hours. This involves not drinking or eating anything except water. We will also ask you to fill in a diary about your mood, how much you are thinking about food, and how hungry you are while fasting.

What are the benefits from taking part?
There are no direct benefits from taking part in the study, but you will be contributing to scientific knowledge and you may find the research session interesting. Study participants will be reimbursed for attending the research session at the rate of £7.50 per hour. UCL undergraduate students can elect to receive course credit instead of payment.

What are the risks from taking part?
It is unlikely that you will experience any distress by taking part in this study, although you may wish to consider the potential effects that fasting might have on you in the short term before agreeing to participate. All of the tasks we will ask you to complete have been used safely in previous research. There are no other anticipated risks of taking part in the study.

How will my information be stored?
All data will be collected and stored anonymously, in accordance with the Data Protection Act 1998.

UCL RESEARCH ETHICS COMMITTEE

Amendment Approval Request Form

1	**ID Number:** 3529/001	**Name and Address of Principal Investigator:** Dr Lucy Serpell, Dept of Clinical Health Psychology, 4th Floor, Torrington Place, London, WC1E 6BT
2	**Project Title: Predicting Individual Responses to Fasting**	
3	**Information about the amendment:** (a) Is the amendment purely administrative? [X] Yes [ ] No [ ] N/A (b) Has the Participant Information Sheet/Consent Form been changed as a result of the amendment? If yes, please enclose a copy. [ ] Yes [X] No [ ] N/A	
4	**Summarise the issues contained in the amendment:** We would like to request that the ethics could be extended a further 12 months. No changes to the experimental design have been made.	
5	**Please give any other information you feel may be necessary:**	
	Signature of Principal Investigator:	**Date of Submission: 25/06/2014**

FOR OFFICE USE ONLY:

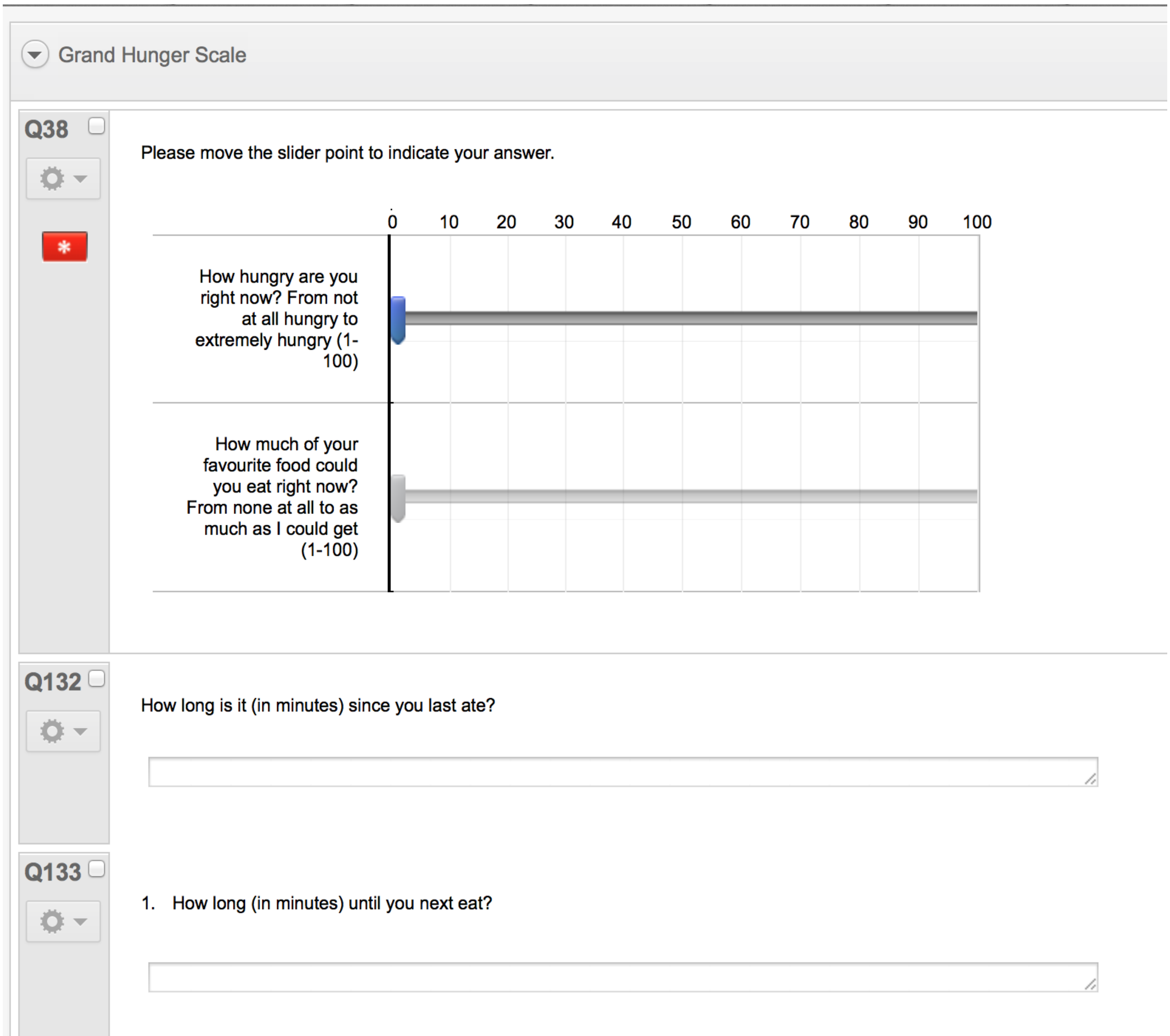
Amendments to the proposed protocol have been …………………… by the Research Ethics Committee.

Chair's Signature: [signature] Date: 25/6/14.

Please return completed form to:

Secretary of the UCL Research Ethics Committee
Graduate School, North Cloisters, Wilkins Building
Gower Street, London WC1E 6BT

Grand Hunger Scale (1968)



Grand Hunger Scale

Q38

Please move the slider point to indicate your answer.

	0	10	20	30	40	50	60	70	80	90	100
How hungry are you right now? From not at all hungry to extremely hungry (1-100)											
How much of your favourite food could you eat right now? From none at all to as much as I could get (1-100)											

Q132

How long is it (in minutes) since you last ate?

Q133

1. How long (in minutes) until you next eat?