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# Loss of control over eating: A systematic review of task based research into impulsive and compulsive processes in binge eating

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## Highlights

- Self-report measures show enhanced impulsivity and compulsivity in binge eating
- Findings on behavioral impulsivity in binge eating are inconsistent
- Findings on behavioral compulsivity suggest a reinforcement learning deficit
- Heterogeneity may be due to the temporal dynamics of symptoms, e.g. related to mood
- Ascertaining psychometric quality of tasks and controlling for BMI is essential

## Abstract

Recurring episodes of excessive food intake in binge eating disorder can be understood through the lens of behavioral control systems: patients repeat maladaptive behaviors against their explicit intent. Self-report measures show enhanced impulsivity and compulsivity in binge eating (BE) but are agnostic as to the processes that might lead to impulsive and compulsive behavior in the moment. Task-based neurocognitive investigations can tap into those processes. In this systematic review, we synthesize neurocognitive research on behavioral impulsivity and compulsivity in BE in humans and animals, published between 2010-2020. Findings on impulsivity are heterogeneous. Findings on compulsivity are sparse but comparatively consistent, indicating an imbalance of goal-directed and habitual control as well as deficits in reversal learning. We urge researchers to address heterogeneity related to mood states and the temporal dynamics of symptoms, to systematically differentiate contributions of body weight and BE, and to ascertain the validity and reliability of tasks. Moreover, we propose to further scrutinize the compulsivity findings to unravel the computational mechanisms of a potential reinforcement learning deficit.

## Abbreviations

|     |                        |
|-----|------------------------|
| BED | Binge Eating Disorder  |
| BE  | Binge Eating           |
| LOC | Loss of Control        |
| NW  | Normal Weight          |
| OW  | Overweight/Obese       |
| BEP | Binge Eating Prone     |
| BER | Binge Eating Resistant |

|        |  |
|--------|--|
| SCID   | Structured Clinical Interview for the diagnoses based on the diagnostic and statistical manual (DSM) |
| MINI   | Mini-International Neuropsychiatric Interview  |
| DIPS   | Diagnostisches Interview bei psychischen Störungen   |
| MIDI   | Minnesota Impulse control Disorders Interview  |
| EDE-Q  | Eating Disorder Examination Questionnaire  |
| EDDS   | Eating Disorder Diagnostic Scale   |
| BES    | Binge Eating Scale   |
| EAT-26 | Eating Attitudes Test  |

**Keywords:** Binge eating, behavioral control, impulsivity, compulsivity, neurocognitive tasks, computational modeling

## 1. Introduction

Binge eating (BE), the consumption of large amounts of food associated with a subjective feeling of loss of control, is very common in the general population. It has an estimated prevalence of around 7% (Brazil, Belgium) to up to 50% (USA, Palestine) (Badrasawi and Zidan, 2019; de França et al., 2014; Lipson and Sonnevile, 2017; Serra et al., 2020). BE occurs transdiagnostically in varying degrees of regularity across eating disorders as well as comorbidly in other psychiatric conditions (e.g. Boulanger et al., 2018; Braun et al., 2019). Binge Eating Disorder (BED), the most common eating disorder (Kessler et al., 2013), lies at the extreme end of the spectrum and is characterized by frequent, distressing binges (Box 1). It is associated with poor mental and physical health outcomes (Kessler et al., 2013; Thornton

et al., 2017; Welch et al., 2016; Yanovski et al., 1993). Thus, patients are at elevated risk for a wide range of other psychiatric disorders (Welch et al., 2016) as well as obesity and associated conditions (Fabricatore and Wadden, 2006; Fairburn et al., 2000; Kessler et al., 2013; Tanofsky-Kraff et al., 2006; Udo and Grilo, 2018; Villarejo et al., 2012). BE as well as BED usually start in adolescence and early adulthood, which enhances the risk for chronicity. Hence, binge eating in the general population, and more categorically reflected in BED, represents a significant public health challenge. Psychological and pharmaceutical treatments are available, but more than one in five patients do not improve significantly after receiving specialized psychotherapy (McElroy et al., 2015). Pharmacological treatments, mostly prescribed off-label, appear to be similarly limited (Reas and Grilo, 2015), although lisdexamfetamine has shown promise in recent years (Heo and Duggan, 2017). In order to improve prevention and care, a more thorough understanding of the development and maintenance of BE is crucial.

The inability to resist the urge to overeat despite negative consequences is pivotal in BED. Patients repetitively engage in this maladaptive behavior against their explicit intent, suggesting that some imbalance of behavioral control is key. Impulsivity and compulsivity are prime candidates here. Impulsivity can be defined as “a predisposition toward rapid, unplanned reactions to internal or external stimuli with diminished regard to [their] negative consequences” (Fineberg et al., 2014). BED patients might be easily distracted from current goals by stimuli that promise reward, and appear to have trouble inhibiting their responses to such stimuli, including food stimuli. Similarly, compulsivity may well contribute to the development and maintenance of BED. It can be defined as the “performance of repetitive and functionally impairing overt or covert behavior without adaptive function, performed in a habitual or stereotyped fashion, either according to rigid rules or as a means of avoiding perceived negative consequences” (Fineberg et al., 2014). The hallmark of BED is such a behavior: repetitive overeating despite known negative consequences. Impulsivity and

compulsivity partially overlap (Chamberlain et al., 2018; Gillan et al., 2016a), so that it is conceivable that both coexist in BED. Consistent with a role in the disorder, there is ample evidence of enhanced self-reported impulsivity – as measured by e.g. the Barratt Impulsiveness Scale (Patton et al., 1995) or the Urgency, Premeditation, Perseverance, Sensation Seeking, Positive Urgency, Impulsive Behavior Scale (Lynam et al., 2006; Whiteside and Lynam, 2001) in BED (Farstad et al., 2015; Kelly et al., 2014; Kollei et al., 2018; Lee et al., 2017; Lyu et al., 2018; Meule and Platte, 2015; Nasser et al., 2004; Oliva et al., 2019; Racine et al., 2015, 2017; Schag et al., 2013; Voon et al., 2015c) (but see also e.g. Carriere et al., 2019). Reporting on self-reported compulsivity in BED is less abundant, perhaps owing to the fact that there are few instruments assessing compulsivity in transdiagnostically, i.e., outside of the context of obsessive compulsive disorder (OCD) (Hook et al., 2021). Instead, questionnaires are often diagnostic (yielding a binary outcome as to the presence of OCD) or assess both compulsions and obsessions in an OCD-specific way (Hook et al., 2021). Nonetheless, there is preliminary work showing an association between BED severity and binge eating related obsessions/compulsions as measured by the Yale-Brown obsessive compulsive scale modified for binge eating (Deal et al., 2015). In addition, there is evidence that individuals suffering from BED score higher on the Yale Food Addiction Scale (Burrows et al., 2017; Carter et al., 2019; Gearhardt et al., 2016, 2009). This can be interpreted as a sign of enhanced addictive-like or compulsive eating, although the concept of food addiction in itself is controversial (Fletcher and Kenny, 2018; Ziauddeen and Fletcher, 2013).

Such reports are extremely valuable when it comes to thinking about how BED patients might lose control of their eating behavior during binges. However, they do not capture the processes that lead to in-the-moment impulsive or compulsive actions. Such mechanistic insight is crucial in order to improve therapies aimed at preventing lapses of control. In this respect, research employing cognitive tasks has a number of advantages. First, tasks can manipulate impulsive and compulsive behavior and thus provide insights into mechanisms. Second, concurrent brain

measures allow relating behavior to its neural substrates. Third, tasks can be used translationally, i.e. in both humans and animals. In animal models, tight control of confounders such as genetic and environmental differences, but also food availability and composition, is possible. Likewise, neurobiological substrates can be accessed more directly thanks to invasive methods (such as single cell recordings, microdialysis). The last decade has seen a rapid proliferation of neurocognitive/-behavioral research on impulsivity and compulsivity in BED – often inspired by addiction models (Everitt and Robbins, 2005; Smith and Robbins, 2013) – in animals and humans. In this systematic review, we survey this work and critically appraise the progress that has been made. Specifically, we ask whether the literature consistently points towards enhanced behavioral impulsivity, compulsivity or both in BE. This would yield mechanistic insights into loss of control during binge eating episodes and help us identify promising neurocognitive markers of BED. This would yield mechanistic insights into loss of control during binge eating episodes and help us identify promising neurocognitive markers of BED. We consider studies comparing human subjects suffering from sub-clinical or clinical BED (but not other eating disorders) and healthy controls, as well as studies comparing normal and binge-like eating animals. Our review extends recent work on the same constructs in anorexia and bulimia nervosa (Howard et al., 2020). It complements other up-to-date reviews (Cury et al., 2020) by including a wider range of tasks as well as animal and functional neuroimaging studies. Importantly, we take a translational perspective: we scrutinize the consistency of findings within translational levels (e.g., in human behavioral studies only), but we also compare and contrast findings across different translational levels. Thus, we note, for example, whether a behavioral finding in rodents holds up in humans, and whether neurofunctional findings have behavioral correlates. Moreover, we embed findings with clinical observations, highlight methodological issues, identify gaps in the literature, and provide recommendations for future investigations.



**Box 1. Definition of Binge Eating Disorder and its Assessment in Humans and Animals**

BED in humans is clinically diagnosed when an individual reports frequent excessive food intake associated with a subjective feeling of loss of control and at least three of (1) eating much more rapidly than normal, (2) eating until feeling uncomfortably full, (3) eating large amounts of food when not feeling physically hungry, (4) eating alone because of feeling embarrassed by how much they are eating, and/or (5) feeling disgusted with themselves, depressed, or very guilty, at least once a week on average, for at least 3 months, without inappropriate compensatory behavior (American Psychiatric Association and Association, 2013). Note that although many patients with BED are obese, elevated BMI is not a diagnostic criterion and some patients are able to maintain a healthy weight.

Animal models of binge like eating behavior typically rely on intermittent access to (mostly palatable) food, in restriction-refeeding cycles (e.g. Oswald et al., 2011), via alternating access to standard chow and palatable food (e.g. Rossetti et al., 2014), or via intermittently granting access to palatable food in addition to standard chow (LeMon et al., 2019), under otherwise standardised conditions. All strategies lead to increased consumption of calories compared to normally fed animals in some, but not all, allowing to sort animals into binge eating prone (BEP) and binge eating resistant (BER) phenotypes.

## **2. Methods**

This systematic review follows recommendations given in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (Liberati et al., 2009).

## **2.1 Information sources and search**

We searched the PubMed database for articles published between January 1<sup>st</sup>, 2010 and December 22<sup>nd</sup>, 2020 using the following search terms: “binge eating” and “response inhibition”, “delay discounting”, “risk decision making”, “decision making”, “motor impulsivity”, “reflection impulsivity”, “interference”, “goal directed”, “set shifting”, and “cognitive flexibility”, respectively. The definition of these search terms was informed by the work of Fineberg et al., (2014) and Stahl et al. (2014), who provide subdivisions of the (behavioral) compulsivity and/or impulsivity constructs along with typical operationalization. We additionally included other relevant articles that we had prior knowledge of.

## **2.2. Eligibility criteria.**

We considered studies in English that reported comparisons between humans or animals with and without binge eating symptoms (full or subsyndromal BED), i.e., case-control studies, on task-based measures of impulsivity and compulsivity. Most of the measures we recognized as operationalization of subdomains of impulsivity and compulsivity were mentioned as such in Fineberg et al., (2014) and Stahl et al. (2014). In addition, we also included measures that were explicitly mentioned to be used to assess the construct in question in the original studies (e.g. the N-back task with lures, which was used to measure interference control in Svaldi et al. (2014b)). We did not include studies on samples with eating disorders other than BED.

## **2.3. Study selection.**

We downloaded the full citations of all articles returned by our search and collected them using Mendeley Desktop, version 1.19.4. We used Mendeley’s built-in utility to remove duplicates that had not been removed automatically on import. We then scanned titles and abstracts of all remaining records and excluded those that did not match our eligibility criteria. Finally, we scanned the full-text articles associated with the remaining records to ensure that eligibility

criteria were indeed met. We identified sets of papers in which the same data was re-published and included only one of each in our tables and qualitative summary.

#### **2.4. Data collection and synthesis.**

For each eligible study in humans, we extracted sample size (per group), mean and standard deviation (or other reported summary statistics) of age and BMI, as well as gender composition of the sample (female only, male only, mixed), paradigms employed and main outcomes. In one case, univariate statistics were not reported; we obtained them by contacting the authors (Kollei et al., 2018). For each eligible study in animals, we extracted sample size (per group), species, sex (female only, male only, mixed), paradigm, and main outcomes. We simplified results so that they are shown in our tables and figures as comparative symbols (<, >, =) depending on the direction and significance of the observed effect.

#### **2.5. Quality assessment**

For each study in humans, MW performed quality assessment according to the Newcastle-Ottawa scale (NOS) for quality assessment adapted for cross sectional studies (Wells et al., 2021). The scale assesses case definition, representativeness of the cases, selection of controls, definition of controls, comparability of cases and controls, ascertainment of exposure, equality of ascertainment for cases and controls, and non-response rate. The maximum number of points (“stars”) a study can achieve is eight, where each category is represented by one star with the exception of comparability, where two stars are possible. We are unaware of scales specifically developed to assess case-control studies in animals and have therefore not performed quality control for these studies.

## 2.6. Paradigms

Many different paradigms have been designed to study different aspects of impulsivity and compulsivity. Here, we provide brief descriptions of those used in studies identified in our literature search.

**Delay and probability discounting.** Delay and probability discounting is a facet of impulsivity (Fineberg et al., 2014; Stahl et al., 2014). In the **monetary choice questionnaire** (Kirby et al., 1999) participants make 27 choices between smaller, immediate rewards and larger, delayed rewards. The choices are fixed. From the responses, a discount parameter  $k$  is computed, describing the hyperbolic discount rate (the larger  $k$ , the steeper the discounting). In the **monetary temporal discounting task** (Rubia et al., 2009), participants choose between smaller, immediate rewards and larger, delayed rewards by button press. There are three delays and 20 trials per delay. The immediate reward is adjusted based on the participants' previous choices, which allows for the calculation of indifference values as well as the discount parameter  $k$  (s.a.). In the **delayed discounting task** (Robles and Vargas, 2007), participants make 240 choice trials between 30 hypothetical cash rewards, with 8 delay magnitudes. Outcome measures are the discount parameter  $k$  or area under the curve. In the **delay and probability discounting tasks used by (Manwaring et al., 2011)**, participants make choices between different amounts of natural and monetary rewards (money, a snack food selected by the participant, a preferred sedentary activity, and massage time). In the delay discounting task, they are told that they could have one of the rewards immediately, the other with a delay (one of five); in the probability discounting task, they are told that they could have one of the rewards for sure, the other with a certain probability (one of five). The amounts of the immediate rewards are adjusted over six trials per delay/probability in order to estimate indifference points or subjective values.

**Risky decision making.** Risky or disadvantageous decision-making is a facet of impulsivity (Fineberg et al., 2014). In the **Iowa Gambling Task** (Bechara et al., 1994),

participants make choices between four decks of cards. Turning decks A and B (disadvantageous decks) yields high wins but also penalties, such that participants incur a net loss over time; turning decks C and D (advantageous decks) yields smaller wins but also penalties, such that participants achieve net wins over time. A and C have more frequent, smaller penalties, whereas B and D have less frequent, larger penalties. Standard outcome measures are the number of advantageous decks (C and D) chosen over all trials or blocks of trials to reflect learning. Fewer advantageous choices can be interpreted as more risky behavior. In the **Cambridge Gambling Task** (Rogers et al., 1999), participants are instructed that at each trial, one of ten red or blue (different ratios) boxes shown on a screen contains a yellow token. They can choose to bet one of five amounts (fixed proportions of their current winnings) on the color of the box containing the token. The betting amounts are presented successively in ascending or descending order, depending on condition. Typical outcome measures are reaction time, quality of decision making (how often the more likely color is chosen) and risk-adjustment (the rate at which participants adjust the betting amount to more favorable ratios of blue and red boxes). In the **Balloon Analogue Risk Task (BART)** (Lejuez et al., 2002), participants can win money by using a pump to inflate images of 30 balloons. The larger the balloon when they cash out, the larger their winnings; however, the balloons have (different) break-points, and when they explode, participants earn no money. The primary outcome measure is the adjusted average number of pumps on unexploded balloons. Higher numbers suggest more risky behavior. In the **Risky Jar Task** (Voon et al., 2015c), participants choose between a jar containing only red balls and a jar containing variable proportions (4 different proportions) of red and blue balls. One ball is randomly chosen from the selected jar; if it is red, participants gain the amount of money specified for each jar. For the risky jar, one of 4 different amounts is displayed. For each prospect (proportion-amount combination of the risky jar), the value of the certain jar is adjusted in a stepwise manner to find the certainty equivalent. The main outcome measure is the probability weight inferred from the certainty equivalents. In the **Game of Dice Task** (Brand et al., 2005), participants throw a single die

eighteen times and place bets on the outcome. They can bet on a single number, or either of two, three, or four numbers. The win/loss probabilities of each option are made explicit. The lower the win probability, the higher the potential gain or loss. The main outcome measure is the number of risky or disadvantageous decisions, i.e. one or two numbers (win probability <50%). In the original **Door Opening Task** (Daugherty and Quay, 1991), participants can open between one and ten doors at every trial to see happy faces (and gain a point) or sad faces (and lose a point). The win probability decreases by 10% per door opened, such that later doors tend to confer more losses than wins (i.e., become riskier). The participants can stop the trial at any time and collect their earnings. The main outcome measure is the number of doors opened. (Preuss et al., 2019) adapted the task to include pictures of low-caloric foods with the happy faces and pictures of high-caloric foods with the sad faces.

**Motor impulsivity.** Motor impulsivity or inhibition is a facet of impulsivity (Fineberg et al., 2014; Stahl et al., 2014). In the **Stop Signal Reaction Time** task (Logan et al., 1984; Verbruggen and Logan, 2008a), participants respond as fast as possible to particular stimuli, unless they see a stop signal (a tone or other stimulus), in which case they must withhold their response. The main outcome measures are stop-signal reaction times, as well as commission errors (failing to withhold the response) and omission errors (failing to show the response). In the **Go-NoGo task** (e.g., Verbruggen and Logan, 2008b), participants respond as fast as possible when presented with so-called go stimuli and withhold responses when presented with no-go stimuli. Typical outcome measures are commission errors (failing to withhold a response) and omission errors (failing to show a response). The **premature response task** (Voon et al., 2014a) is a task modeled on the 5-choice-serial-reaction-time task used in rodents. When shown four boxes on a touchscreen, participants are told to press and hold a key until they see a green target circle in one of the boxes, upon which they must release the key and touch the target box as quickly as possible to gain money. The main outcome measure is premature release of the key prior to target onset.

Reflection impulsivity. Limited reflection before making a decision is a facet of impulsivity (Fineberg et al., 2014). In the **information sampling task** (Clark et al., 2006), participants are faced with 25 grey boxes, each of which contains one of two colors. To win money, they must correctly guess, after opening as many boxes as they wish, which color the majority of the boxes hide; incorrect responses result in losses. In one condition, the reward is fixed, in the other, the available reward decreases with boxes opened. Typical outcome measures are correct and incorrect choices, reaction times, and the mean number of boxes opened per trial.

Interference control. Limited capacity to control the influence of interfering stimuli (proactive, response, and stimulus interference) is a facet of impulsivity (Stahl et al., 2014). In the **recent probes task** (e.g. Svaldi et al., 2014b), participants must, at each trial, memorize a set of stimuli and decide whether a probe was part of the set after a brief retention interval. Sometimes, the probe was not contained in the current set but in the one from the immediately preceding one, such that performance is subject to interference. Typical outcome measures are the difference in reaction times to recent vs non-recent non-matching probes as well as accuracy. In the **n-back task with lures** (e.g., Svaldi et al., 2014b), participants are successively presented with a series of stimuli. After a while, they are presented with a probe and asked whether it had been shown  $n$  trials earlier. Lures are probes which had been presented  $n+1$  or  $n-1$  trials earlier. Typical outcome measures are accuracy and reaction time. In the **anti-saccade task** (e.g., Schag et al., 2013), participants are presented with stimuli (disorder-relevant or irrelevant) on one side of a screen and told to avert their gaze as quickly as they can. Outcome measures are directional errors in the first and second saccade. In the **(Eriksen) Flanker task** (Eriksen and Eriksen, 1974), participants respond to a stimulus at the center of a screen with one of two instructed actions (e.g., press left or press right). The target stimuli are flanked by either congruent stimuli (i.e., stimuli which require the same response), incongruent stimuli (i.e., stimuli which require a different response), or neutral stimuli (which

require no response). Typical outcome measures are reaction times and accuracy. In the original **Stroop task** (MacLeod, 1991; Stroop, 1935), participants are asked to read aloud color words that are either congruently or incongruently colored (e.g. the word “green” written in green or red). The main outcome measure is the difference in reaction time between congruent and incongruent conditions as well as accuracy. The task has been adapted for a food context. Here, participants are asked to name the color food and non-food words are written in. The main outcome measures are again reaction time and accuracy (e.g., Preuss et al., 2019).

Goal-directed control. Relative insensitivity to outcomes or goals is a facet of compulsivity (Fineberg et al., 2014). In **devaluation sensitivity** paradigms, animals learn to emit a specific response to obtain a reward (e.g. sucrose), which is later devalued (e.g. through ad libitum access). The task assesses continued responses after devaluation (e.g. number of lever presses in a fixed time period after devaluation). In the **Two-step task** (Daw et al., 2011), participants try to win money by making two binary choices between abstract stimuli at each trial. The first-stage choice probabilistically leads to one of two possible second stage choice options, such that there is a rare and a common transition. The second-stage choice is rewarded with different probabilities depending on the stimulus chosen. To encourage ongoing learning, the win probabilities of the second-stage options continually change based on gaussian random walks. The main behavioral outcome measure is the interaction effect between second-stage feedback and transition type (rare or common) on the probability of sticking with the same first-stage choice: a large interaction effect indicates goal-directed or model-based control. Computational modeling yields further outcome measures such as a weighting parameter  $w$  which quantifies the contribution of goal-directed or model-based control.

Contingency related cognitive flexibility. Relative behavioral inflexibility in response to changing reward contingencies is a facet of compulsivity (Fineberg et al., 2014). **Aversive conditioning** is a standard animal paradigm where animals are trained to associate a



(pleasant) behavior, e.g. eating sucrose, with unpleasant outcomes such as footshocks. The latency of learning can be interpreted as perseveration. In **probabilistic reversal learning** tasks (e.g., Cools et al., 2002), participants learn to choose one stimulus over another based on its probability of yielding positive feedback (typically monetary). After a while, the reward contingencies reverse: the participants must relearn the stimuli's values and flexibly adjust their responses. Several different versions exist with different numbers of reversals and where the time between reversals is either fixed or based on a learning criterion.

**Set-shifting.** Relative behavioral or attentional inflexibility in response to changing task demands is a facet of compulsivity (Fineberg et al., 2014). In the **“Behavioral Assessment of the Dysexecutive Syndrome” (BADS) rule shift task** (Wilson et al., 1996), participants are successively presented with 21 playing cards. They are instructed to respond “yes” to red cards and “no” to black cards in the first part of the task; and to respond “yes” if the current card has the same color as the previous one and “no” otherwise in the second part, which requires flexible adaptation. Reaction time and accuracy are the main outcome measures. In the **intra-extradimensional set shifting task** (Downes et al., 1989), participants are asked to choose, at every trial, between two patterns of stimuli which vary along two dimensions (e.g. color and shape). To make the correct choice, participants must work out the underlying rule, which changes several times over the course of the task. The task covers contingency reversals, intradimensional shifts (where exemplars, but not the rule-relevant dimension change), and extradimensional shifts (where exemplars and the rule-relevant dimension change) in subsequent blocks that can be reached after a learning criterion is reached. The main outcome measures are accuracy, reaction times, and number of blocks and trials completed. In the **Penn conditional exclusion task** (Kurtz et al., 2004), participants choose, at each trial, one of four figures that is different from the other three. The correct response is based on one of three rules, which the participant must work out. The main outcome measures are total number of categories (rules) achieved, errors, trials to first category, and total number

of trials. In the **Trail-Making Task Part B** (TMT-B) (Reitan, 1958, 1955), participants must draw a line connecting 25 circles marked with numbers between 1 and 13 and letters between A and L, as quickly as possible, in ascending order, alternating between numbers and letters (i.e., 1-A-2-B etc.). The main outcome is the latency by which participants complete the test. In the **Wisconsin card sorting task** (Berg, 1948), participants are presented with 4 sample cards and one probe card and are asked to match the probe to one of the sample cards. The sample cards differ in terms of the color, shape, or number of stimuli on them. Participants must work out the current matching rule based on trial-by-trial feedback. After a fixed number of correct responses, the rule shifts and participants must adapt their strategy. Typical outcome measures include rules achieved, trials, errors, and perseverative errors.

### 3. Results

#### 3.1. Study selection and overall quality assessment

We identified a total of 559 relevant records, 57 of which we ultimately included (for details of the selection process, see Figure 1). At the final stage of selection, we identified two pairs of articles in which data was re-published (Manasse et al., 2015a, 2015b; Schag et al., 2019, 2013); we included only one of each in our synthesis.

The majority of studies had adequate quality as assessed by the NOS score (5 or 6 stars). No study achieved more than 6 stars. Very few studies had explicitly representative samples and none reported non-response rates for cases and controls separately. Studies that achieved under 5 stars mostly did so because of incomplete or unclear reporting of methods or failure to control for important variables such as BMI or age. For the number of stars achieved by each study, see Tables 1 through 7.

### 3.2. Impulsivity

A variety of cognitive tasks have been designed to capture different but interrelated aspects of the impulsivity construct: choice impulsivity (e.g. delay discounting tasks), risky decision making (e.g. gambling tasks), motor impulsivity (e.g. Stop-Signal / Go-NoGo tasks), and reflection impulsivity, i.e. the tendency to gather and evaluate information prior to decision-making (Clark et al., 2006) (e.g. the Cambridge Information Sampling task), as well as susceptibility to interference by stimuli prior to or during task performance (e.g. recent probes task and Stroop task, respectively), and during response selection (e.g. Flanker task) (Fineberg et al., 2014; Stahl et al., 2014). All of these facets of impulsivity have been investigated in relation to binge eating (both subclinical and full-blown BED). Where available, we synthesize evidence from animal studies first and compare it with evidence from human subjects. Where possible, we also report on psychophysiological correlates.

**3.2.1. Choice impulsivity/Delay and probability discounting.** As shown in Figure 2.A., there is evidence of steeper delay discounting, i.e., a preference for smaller, earlier rewards, in binge eating prone (BEP) rats (Cano et al., 2016; Vickers et al., 2017) (although see Moore et al., 2018). Consistent with this, the literature also predominantly points towards enhanced discounting in human BED subjects compared to normal weight (NW) controls (Davis et al., 2010; Mole et al., 2015; Steward et al., 2017)(although see Bartholdy et al., 2017a; Yan et al., 2018). However, it is less clear whether this is driven by loss of control (LOC) eating or weight status. Indeed, while some studies do find deficits compared with weight matched controls (Manasse et al., 2015b; Manwaring et al., 2011), others do not (Blume et al., 2018; Davis et al., 2010; Mole et al., 2015), casting doubt on the specificity of the effect. For study characteristics, see Table 1.

**3.2.2. Decision making under risk/uncertainty.** Decision making under risk/uncertainty has not yet been investigated in animal models of BED. In humans, investigations are ample, but the results are inconclusive (Figure 2.B). On the Iowa Gambling Task and equivalent

paradigms, some studies find enhanced maladaptive decision making under uncertainty in BED compared to NW (Aloi et al., 2020, 2015; Danner et al., 2013, 2012; Davis et al., 2010) and overweight (OW) controls (Córdova et al., 2017; Muller et al., 2014). Others find no such differences comparing BED to NW (Dingemans et al., 2019; Grant and Chamberlain, 2019; Kittel et al., 2017; Kollei et al., 2018) or OW controls (Aloi et al., 2020; Blume et al., 2018; Danner et al., 2012; Davis et al., 2010; Grant and Chamberlain, 2019; Kittel et al., 2017). In studies employing less common paradigms, enhanced risk taking was observed in some samples (Svaldi et al., 2010; Voon et al., 2015c) but not others (Manasse et al., 2015b; Preuss et al., 2019; Wu et al., 2013). Thus, it remains uncertain what role risky decision-making might play in BED. For study characteristics, see Table 2.

**3.2.3. Motor impulsivity.** To our knowledge, no animal studies have yet directly compared rodents with normal and binge-like feeding patterns on motor impulsivity. However, converging evidence suggests that “waiting” impulsivity (the ability to withhold a response) predicts binge size in rats on a BE protocol (Anastasio et al., 2019; Velázquez-Sánchez et al., 2014). In humans, no group differences in “waiting” impulsivity were observed between BED subjects and OW or NW controls in the sole study that assessed it (Voon et al., 2014b). Motor impulsivity is more frequently assessed as “stopping” impulsivity (the ability to abort a response) in humans, using the Go-NoGo or stop signal reaction time tasks (SSRTT). On these and equivalent tasks, many studies report altered motor impulsivity associated with binge eating (Córdova et al., 2017; Grant and Chamberlain, 2019; Hege et al., 2015; Lyu et al., 2017; Manasse et al., 2016; Mobbs et al., 2011; Mole et al., 2015; Preuss et al., 2019; Svaldi et al., 2014a). However, across studies, these alterations are often seen on different metrics of the same task, between different weight status groups, or in food/non-food versions of the tasks (Figure 2.C), so that the effects are not strictly comparable. In addition, an almost equal number of studies reports no differences (Antunes et al., 2020; Bartholdy et al., 2019, 2017b; Blume et al., 2018; Kollei et al., 2018; Loeber et al., 2018; Oliva et al., 2019; Wu et al., 2013).

Neuroimaging studies on the Go-NoGo task indicate decreased activation of the middle frontal gyrus/dorsolateral PFC during NoGo trials in BED (Hege et al., 2015; Oliva et al., 2019). This was suggested to reflect difficulty recruiting necessary control resources, but was only related to behavior in one investigation (Hege et al., 2015). On the SSRT, BE has been associated with altered activity during stop trials in the middle frontal gyrus (Oliva et al., 2019), but this finding could not be related to behavior. Thus, the animal literature suggests a relationship between motor impulsivity and binge eating, but inconsistencies abound in the human behavioral and psychophysiological data, precluding straightforward interpretation. For study characteristics, see Table 3.

**3.2.4. Reflection impulsivity.** Compared to other aspects of impulsivity, interest in reflection impulsivity in BE has been scant. Only one study has looked at it so far (Figure 2.D). On an information sampling task, human BED subjects did not differ from NW controls and outperformed OW controls (Mole et al., 2015). Preliminarily, this suggests no specific impairment associated with LOC eating in this domain. For study characteristics, see Table 4.

**3.2.5. Interference control.** Like reflection impulsivity, interference control has not yet been investigated in animal studies on BED. In humans, all of its three subdomains – stimulus, response, and proactive interference – have been studied, but the results are inconclusive (Figure 2.E). Group differences in stimulus interference, as assessed using the Stroop task or equivalent paradigms, have been documented (Kittel et al., 2017; Manasse et al., 2015b), but most studies report no differences between BED and NW (Balodis et al., 2013; Lee et al., 2017) or OW controls (Balodis et al., 2013; Dingemans et al., 2019; Duchesne et al., 2010; Eneva et al., 2017; Galioto et al., 2012; Preuss et al., 2019). This is irrespective of whether a traditional or a food version was used. Neuroimaging data suggests reduced activity in ventral parts of the PFC and the insula during incongruent Stroop trials (Balodis et al., 2013), and enhanced activation of the ventral striatum and postcentral gyrus in response to food stimuli in the Stroop Task (Lee et al., 2017) in BED. However, since these neuronal differences were

not related to behavior, interpretations of these findings as reflecting diminished inhibitory control or enhanced bottom-up processing are speculative. The few studies on response interference, measured using the Flanker task, yield conflicting results regarding performance differences between BED subjects and controls (Eneva et al., 2017; Lyu et al., 2018). Likewise, there is evidence of reduced as well as intact performance, respectively, on tasks assessing distractibility or proactive interference in BED. Thus, patients have more difficulty than OW controls on the N-Back with lures and the anti-saccade task (Schag et al., 2013; Svaldi et al., 2014b), but perform equally well on a recent probes task (Svaldi et al., 2014b). In sum, the literature on interference control is inconclusive as to a potential deficit in BED. For study characteristics, see Table 5.

**3.2.6. Interim Conclusion.** Overall, we note that the literature on impulsivity in BED is extremely heterogeneous. There is little continuity across translational levels (from animal to human and from behavior to neural underpinnings). In addition, behavioral results are inconsistent across and within subconstructs of impulsivity. The sample composition in terms of age and gender, as well as the use of food vs non-food stimuli does not seem to have consistent effects on whether enhanced impulsivity emerges in BE samples or not. Similarly, differences do not emerge exclusively in comparison with OW or NW controls, respectively, which would point to a BMI confound. Given such indeterminate evidence, it is difficult to draw firm conclusions on the processes underlying impulsive failures of behavioral control in BED.

### **3.3. Compulsivity**

The wealth of studies on compulsive behavior in BED falls far behind impulsivity-centered investigations. This is perhaps not surprising because some of its features are difficult to produce in a laboratory setting. Thus, habits are notoriously difficult to induce in humans (de Wit et al., 2018) – even more so if they are to withstand punishment. Likewise, we are unaware of neurocognitive tasks that probe stereotypes or the anxiolytic effect of compulsive behavior

in BE. Nonetheless, a range of tasks has been employed to assess central aspects of compulsivity: the balance of goal-directed and habitual control (e.g., two step decision task), reward related cognitive flexibility (e.g., probabilistic reversal learning task), and task set related cognitive flexibility (e.g. Wisconsin Card Sorting Task). Where available, we synthesize evidence from animal studies first and compare it with evidence from human subjects.

**3.3.1. Goal directed and habitual control.** Goal-directed control is the ability to plan, carry out, and adjust actions in accordance with current goals, as opposed to following previously learned stimulus-response patterns (habitual control). In animal studies, this is typically assessed using devaluation protocols. There is converging evidence that binge eating behavior in rats is associated with reduced sensitivity to devaluation, such that the animals continue to respond to obtain food despite devaluation (Figure 2.F) (Furlong et al., 2014; LeMon et al., 2019; Parkes et al., 2017). Crucially, this seems to be specific to instrumental behavior and not due to altered consummatory preference (LeMon et al., 2019; Parkes et al., 2017). This suggests that the animals fail to act in accordance with their goals but driven by habit. In humans, habitual control in BED has received only little attention so far. One group reports relatively greater reliance on habitual rather than goal directed behavioral control on the two-step decision-making task (Daw et al., 2011) in BED subjects, compared to both NW and OW controls (Figure 2.J) (Voon et al., 2015b). This effect was evident both at the level of choice data and supported by computational modelling. It could not be replicated in a subsequent study (Voon et al., 2020). However, it should be noted that this latter study had a very small BED sample (N=7). Both studies report enhanced, feedback-independent choice perseveration (Voon et al., 2020, 2015a). For study characteristics, see Table 6.

**3.3.2. Cognitive flexibility.** Cognitive flexibility tasks require agents to adapt their responses to changing environments. Reward or contingency related cognitive flexibility, i.e., the ability to adjust to changing reward values, seems to be impaired in BE (Figure 2.G). There is solid evidence that binge eating is associated with reduced sensitivity to aversive conditioning in

rodents (Heal et al., 2016; Moshe et al., 2017; Oswald et al., 2011; Rossetti et al., 2014; Velázquez-Sánchez et al., 2015). This effect does not seem to be specific to immediate, external aversive outcomes (such as footshocks) but also occurs when the aversive outcome is delayed and gastrointestinal (lactose “poisoning”) (Moshe et al., 2017). In translational terms, this is important because this type of outcome more closely resembles the physical and psychological discomfort humans experience after binges. Consistently, binge eating rats have been shown to have trouble relearning changing reward contingencies in a reversal learning task, where they perseverated on a previously rewarding option more than did controls (Chawla et al., 2017). Likewise, human subjects with BED have also shown worse reversal learning performance than weight matched controls (Reiter et al., 2017). However, interestingly, this seemed to be driven by maladaptively enhanced switching between options rather than perseveration. This is suggestive of animbalance between exploration and exploitation opposite to the perseveration (overexploitation) seen in rats. Supporting this interpretation, the authors also performed computational modelling, which yielded a higher choice stochasticity – indicative of greater exploration behavior – in the BED group, and found reduced activation of the right anterior insula/vIPFC during explorative trials. Partially convergent, another research group found a similar tendency to switch more between options in BED patients than NW controls in a one-reversal version of the task, although they observed no straightforward performance differences (Banca et al., 2016). Yet another study found that BED have a greater tendency to explore options than OW controls on a different task (Morris et al., 2016). This suggests that BED may be characterized by enhanced but maladaptive exploration that hinders cognitive flexibility. However, the above findings are complicated by differential observations in different weight-status groups and motivational contexts and should be interpreted carefully.

The picture is more muddled in tasks assessing set related cognitive flexibility or set-shifting, where agents have to switch between goals or shift their attention (Figure 2.H). Regardless of



the specific tasks used, some research groups find differences in performance between BED subjects and NW (Aloi et al., 2020, 2015; Banca et al., 2016) or OW (Duchesne et al., 2010; Svaldi et al., 2010) controls, respectively. Others report no such differences compared to either NW (Dingemans et al., 2019; Eneva et al., 2017; Kelly et al., 2013; Kittel et al., 2017; Kollei et al., 2018; Reiter et al., 2017) or OW controls (Banca et al., 2016; Blume et al., 2018; Eneva et al., 2017; Galieto et al., 2012; Kittel et al., 2017; Kollei et al., 2018; Manasse et al., 2015b). Thus, whether or not set-shifting difficulties play a role in BED remains an open question. For study characteristics, see Table 7.

**3.3.3. Interim Conclusion.** Compared to what we saw in the impulsivity literature, the evidence on compulsivity in BED is relatively consistent regarding some subdomains (Figure 2.H-J). Binge eating associated alterations in reward related cognitive flexibility emerge across translational levels, i.e. in rodent studies as well as human behavioral and neurofunctional studies, as do alterations of goal-directed and/or habitual control. In contrast, the literature on set shifting is very heterogeneous, and does not exhibit patterns that would point to differences between samples or stimulus material as a source of this variability. Thus, the evidence on compulsive behavior in BED primarily points towards enhanced reward- and punishment-related compulsivity (disrupted reward-related cognitive flexibility and goal-directed behavioral control). However, we note that far fewer studies have investigated aspects of compulsivity than impulsivity, and that results remain to be replicated.

## 4. Discussion

Although there is solid evidence of enhanced self-reported impulsivity in BED, the surveyed literature indicates that this could not be shown consistently using behavioral tasks. We found little continuity across translational levels. Comparable studies yielded conflicting results in nearly all subconstructs considered. By contrast, we found that the more brittle evidence of

self-reported compulsivity in BED tended to be at least partially reflected in behavioral findings, in both humans and animal models of the disorder. Thus, rodent and human studies convergently show relatively impaired reward related cognitive flexibility and enhanced reliance on habitual control.

#### **4.1. Heterogeneity within the impulsivity literature.**

The fact that we did not find consistent evidence of enhanced impulsive behavior in our review, in spite of self-report evidence to the contrary, is not necessarily surprising. Several studies have shown that self-report and behavioral measures of impulsivity do not correlate well and might indeed measure different constructs (Cyders and Coskunpinar, 2011; Reynolds et al., 2006; Stahl et al., 2014). By contrast, the heterogeneity of findings within the behavioral literature itself is remarkable and unexpected. It severely curtails the interpretability of individual findings and should be addressed. Meta-analytic approaches are helpful to gauge overall effect sizes, and indeed, for some sub-domains of impulsivity, meta-analyses have been performed. Thus, Amlung et al. (2019) find enhanced temporal discounting in BED, although they focus on comparisons against normal weight controls, leaving aside possible confounds with BMI. Cury et al. (2020) report no significant differences between BED subjects and controls on the SSRT, Stroop task, and gambling tasks. However, importantly, neither are able to pin down the reason(s) for the divergent results across the original studies. In addition to confounding effects of comorbidity, treatment, sample type and possible p-hacking that Cury et al. (2020) suggest, we propose that this heterogeneity may be due to a disregard for a specific clinical feature of BED, methodological limitations or a combination of both (detailed below):

It is something of a truism that loss of control in BED is not constant but state-dependent, and this is taken into account in many studies. Yet it is often tacitly assumed that the loss of control experienced by BED patients is similar to the loss of control experienced by e.g. drug or alcohol

users, i.e., often triggered by disorder relevant cues in the environment (see e.g. Berridge and Robinson, 2016; Cofresí et al., 2019 for reviews). Indeed, we do see enhanced food cue reactivity or attentional bias towards food cues in BED (Deluchi et al., 2017; Lyu et al., 2016; Popien et al., 2015; Schag et al., 2013; Schmidt et al., 2016; Schmitz et al., 2015, 2014; Sperling et al., 2017). Hence, food stimuli are often used in paradigms assessing impulsivity in BED. But there is little evidence of enhanced motor impulsivity in the face of or interference by food stimuli, suggesting that this bias does not straightforwardly translate into a control deficit, although explicit investigations of the influence of food stimuli on the other aspects of impulsivity are as yet missing. Instead, negative mood states may be more essential in BED. Mood disorders are common comorbidities in BED (Hudson et al., 2007). Likewise, a well-established finding from studies using self-report instruments is that patients have high “negative urgency”, i.e. a tendency to act impulsively when distressed (Kelly et al., 2014; Kenny et al., 2019; Racine et al., 2015; Ralph-Nearman et al., 2020), which also correlates with symptom severity. This aspect is not usually captured by the paradigms used to measure impulsivity in task-based designs, which may have contributed to the heterogeneity within the impulsivity literature. To account for this, negative mood as a potential favorable condition or trigger for in-the-moment loss of control must be experimentally manipulated. For example, negative mood could be induced either within a task, e.g. through a large loss in a wheel of fortune draw (e.g. Eldar and Niv, 2015) or prior to it, e.g. by watching a film (Westermann et al., 1996). Notably, Danner et al. (2013) have done the latter and found an increase in impulsive behavior after punishments in BE participants after a negative mood induction. Other state factors may also play a role in triggering loss of behavioral control, such as physiological or hedonic hunger. Incorporating such factors may help improve consistency across studies in the future.

In addition, certain methodological issues may have played a part in producing heterogeneous results across studies. First, because BED frequently overlaps with obesity (Hudson et al.,

2007; Kessler et al., 2013), there is a great risk of confounding effects of BMI and LOC eating. Thus, group differences might emerge in comparisons of BED participants against NW controls but vanish in comparisons against OW controls. Although many studies have compared all three groups (BED, and NW and OW controls), this practice is not yet pervasive and may have exacerbated the muddled picture we see. Second, in cross-sectional studies like those considered here, samples typically include individuals at varying stages of the illness. This means that changes in the cognitive profile that might parallel illness progression are disregarded. For example, a more compulsive profile in BED could develop from a more impulsive profile, not unlike what has been suggested in the addiction literature (Belin et al., 2008). Such an effect would be masked in cross-sectional studies and might result in inconsistent findings across samples. Third, the tasks employed might be unreliable. Low reliability dramatically reduces correlations between task readouts and individual differences such as symptom dimensions (Hedge et al., 2018). Indeed, many of the tasks that have been used to assess impulsivity in BED have poor retest reliability, e.g. the IGT (Buelow and Barnhart, 2017), Game of Dice (Buelow and Barnhart, 2017), and SSRT (Hedge et al., 2018) (for an overview, see Enkavi et al., 2019; Hedge et al., 2018). While such methodological issues do not apply exclusively to studies on impulsivity in BED, they may be of particular importance here.

Hence, although findings regarding impulsivity in LOC eating and BED are quite incongruous, the idea that it might contribute to loss of control over eating behavior cannot be dismissed yet. Future studies should attempt to distil its role using more careful designs. Negative mood as a potential catalyst for impulsive behavior in BED should be taken into account and explicitly manipulated experimentally. Additionally, great care should be taken to control for the differential effects of excess weight and LOC eating; to ascertain that the tasks employed are reliable; and to capture disease dynamics. The latter could be achieved by statistically modelling illness duration, by conducting longitudinal studies, or by studying adolescent/early

adulthood samples, as this is the period when BED typically arises and effects of chronicity are unlikely to occur (Hudson et al., 2007; Kessler et al., 2013; Manwaring et al., 2006; Mustelin et al., 2015; Spurrell et al., 1997).

#### **4.2. Enhanced compulsivity in BED?**

The literature on compulsive behavior in BED is less ample than the impulsivity literature and many findings remain to be replicated. Nonetheless, in keeping with the notion of binge eating as a compulsive behavior (Gillan et al., 2016b; Kakoschke et al., 2019; Moore et al., 2017; Voon et al., 2015b), we found relatively consistent evidence of impaired goal-directed control and cognitive flexibility in BE. The latter is evident mainly in tasks where participants must adapt their behavior to changing rewards and punishments (reward-related cognitive flexibility), and less so in tasks where participants must merely shift attention or decision-making based on changing rules (set-shifting). Reinforcement learning is crucially implicated in both reward-related cognitive flexibility and goal-directed control tasks, where behaviors were explicitly rewarded or punished. The evidence thus lends itself to the speculation that reinforcement learning difficulties might play a role. That is, certain failures of behavioral control in BED may be linked to alterations of the way previous experiences of reward and punishment are integrated when making decisions in the present.

One way to investigate this is by drawing on biologically plausible computational reinforcement learning models (i.e., algorithms that imitate behavior) when analyzing task data (e.g. Morris et al., 2016; Reiter et al., 2017; Voon et al., 2015a). Fitted to the individual's data, the parameters of a model can yield insights as to the mechanistic differences that might underly divergences in behavior. Early results using this approach indicate a distortion of how punishments, in contrast to rewards, shape reinforcement learning in BE (Banca et al., 2016; Morris et al., 2016). Moreover, they suggest that BED patients have difficulty adaptively exploiting their knowledge of the rewarding or punishing consequences of actions when

making decisions (Morris et al., 2016; Reiter et al., 2017), as well as their knowledge of the (task) environment when it comes to planning actions in a goal directed manner (Voon et al., 2015b).

Integrating these insights into the framework of impulsivity and compulsivity can be difficult. For example, they suggest that low performance on a reversal learning task in BE came about as a result of excessive switching between response options (Reiter et al., 2017) – an instable behavioral pattern reflective of maladaptive exploration. In contrast to perseveration, over-exploration appears impulsive rather than compulsive, and has in fact been associated with impulsive disorders such as ADHD in the past (Hauser et al., 2014). This challenges any sharp divide between compulsivity and impulsivity. Indeed, a recent line of factor analytic work in large samples suggests that they overlap at least partially (Chamberlain et al., 2018; Gillan et al., 2016a; Tiego et al., 2019). One study indicates that three latent factors may be in play (Tiego et al., 2019). First, “impulsivity”, characterized especially by risk and reward seeking as well as lack of forethought; second, “compulsivity”, characterized by risk aversion and harm avoidance as well as increased need for premeditation; and third, “disinhibition”, characterized by impulsivity (as per the UPPS), behavioral approach, intolerance of uncertainty and obsessive beliefs (Tiego et al., 2019). Partly because this work has not yet been extended to the realm of task-based impulsivity and compulsivity metrics, partly for the sake of readability, we have assigned tasks to one domain or the other in our review. However, future research may benefit from a focus on the neurobehavioral substrates that impulsivity and compulsivity share (e.g. reduced goal-directed control) and the processes that may uniquely dissociate them (e.g. choice switching versus perseveration) (Deserno and Hauser, 2020). To do this, it will be important to identify fine-grained metrics that reflect distinct components of task performance.

Going forward, alterations that have already been observed should be further investigated using a two-pronged strategy. One line of research should explore them in more detail, asking

how they relate to neurochemical differences observed between patients and controls (Joutsa et al., 2018; Majuri et al., 2017, 2016). Likewise, it should be tested whether they might be more pronounced in punishment-avoidance contexts, consistent with reports of increased desire to (binge) eat in negative mood and stress states in BED (Rosenberg et al., 2013; Schulz and Laessle, 2012). This is possible thanks to newly developed tasks and models that can capture state-dependent mood as well as neurochemical effects (Eldar and Niv, 2015; Michely et al., 2020). The other line of research should examine their relationship with clinical outcomes, asking e.g. how they relate to its prominent clinical onset in adolescence, and whether they wax and wane with BED symptom severity, in keeping with a mechanistic role in the disorder.

#### **4.3. Translational Shortcomings.**

In addition to the specific remarks above, we note that there is little in the way of translational work (with a few notable exceptions). Thus, there are few animal studies overall, but particularly in the impulsivity domain, as well as a relative lack of studies attempting to directly replicate rodent findings in humans or vice versa. Likewise, there are few neurofunctional investigations, despite growing evidence of substantial neurostructural and neurochemical alterations in BED (Cambridge et al., 2013; Dodds et al., 2012; Filbey et al., 2012; Fleck et al., 2019; Joutsa et al., 2018; Majuri et al., 2017, 2016; Schäfer et al., 2010; Wang et al., 2011). This should be addressed in the future. Moreover, in the few studies that did report neuroimaging data in addition to behavioral data, the latter could often not be related to the former (Balodis et al., 2013; Lee et al., 2017; Oliva et al., 2019). This could once more reflect a problem with poor task reliability, which invariably reduces correlations with other measures, including neuroimaging measures (Elliott et al., 2020; Hedge et al., 2018). We can therefore not stress enough that it is essential that we use reliable tasks when investigating individual differences in behavior and their associated brain signatures.

#### 4.4. Limitations

In this review, we focused on case-control studies looking into differences between groups of individuals with binge eating symptoms (or more frequently binge eating disorder) and either normal- or overweight. This approach is limited on three accounts. First, limiting comparisons to one category of disorder with healthy individuals precludes the discovery of transdiagnostically similar alterations of behavioral impulsivity and compulsivity, e.g. across eating disorders or with substance misuse disorders, attention deficit hyperactivity disorder, or obsessive compulsive disorder. However, we have reason to believe from self-report based studies that the overlap is considerable (Tiego et al., 2019). This should be taken into account in the future. Second, binge eating occurs transdiagnostically across eating disorders. Although this is clinically relevant, our approach meant that we could not include studies on people with e.g., bulimia nervosa or anorexia. This is because loss of control eating cannot be differentiated from other symptoms (e.g., compensatory behaviors) in those populations. Similarly, we could not include direct comparisons between eating disorder phenotypes because they confer information mostly about the features that distinguish them rather than those that they share (e.g. binge eating). Third, and relatedly, disregarding correlations with symptom severity runs the risk of overlooking subtle associations as well as overinterpreting group differences that turn out not to be associated with symptom severity.

We have taken this approach in order to maintain focus. However, there are more and more well-powered, population-based studies that sample multiple metrics at once – such as different symptom scales and self-report but also task-based metrics of impulsivity and compulsivity (e.g. Gillan et al., 2016a). This allows for simultaneous comparison of the relationship of different types of psychiatric symptoms with these metrics. In addition, it allows for comparisons between the metrics themselves, yielding vital insights into their relationship with one another. Hook et al., (2021) recently stressed the importance of using transdiagnostically valid scales of compulsivity in such work, a suggestion that will hopefully



be taken up. Future reviews will be able to take a more transdiagnostic and dimensional view, which promises to be fruitful.

In addition, we have chosen not to perform meta-analysis, precluding the quantification of effects across studies. We made this decision because a recent review and meta-analysis on executive function in BED covers many of the tasks relevant to impulsivity and compulsivity for which meta-analysis is possible, i.e., motor impulsivity, risky decision-making, interference control, and set shifting (Cury et al., 2020). Another covers delay discounting (Amlung et al., 2019). For the other domains, e.g., reflection impulsivity, reward-related cognitive flexibility, or goal-directed control, the number of studies was insufficient to perform meta-analysis. Notwithstanding, we feel that our more qualitative approach incorporating animal and psychophysiological work adds important perspectives that meta-analyses alone do not afford.

Finally, we have not included studies on neurostructural and neurochemical alterations in BED, nor have we considered treatment studies. Yet such alterations are likely relevant to impulsive and compulsive behavior. While this would have gone beyond the scope of the current review with its clear focus on behavioral data, it would be valuable to integrate these insights in the future.

#### **4.5. Conclusion and recommendations for future studies.**

Self-report measures point towards enhanced impulsivity and compulsivity in BED, but they are agnostic as to the mechanisms that might lead to impulsive and compulsive behavior in the moment. Task-based research promises insight here, but our review shows that the literature on impulsive behavior in BED is extremely heterogeneous and does not yield unequivocal conclusions. The literature on compulsive behavior implicates a potential role of a reinforcement learning deficit. We propose that future research should focus on (1) taking into account momentary mood state as a possible catalyst of impulsive, and potentially also compulsive behavior; (2) more consistently controlling for confounding variables such as BMI;

(3) capturing disease dynamics in longitudinal designs or by controlling for illness duration, ideally in developmental samples; (4) using reliable behavioral measures so as to be able to pick up correlations with individual differences and brain responses; (5) translating animal work to humans and back, and behavioral to neuroimaging studies; and (6) further interrogating the relatively consistent findings in the compulsivity domain, especially in view of a potential role of a reinforcement learning deficit. To do this, we suggest adopting computational approaches, which can yield clues as to process alterations that might lead to behavioral differences, and can be applied across measurement modalities in human and animal studies (Alsiö et al., 2019; Gläscher and O'Doherty, 2010; Groman et al., 2019; Hirokawa et al., 2019) .

#### Disclosures

MW, LD, NH, and AH report no biomedical financial interests or potential conflicts of interest.

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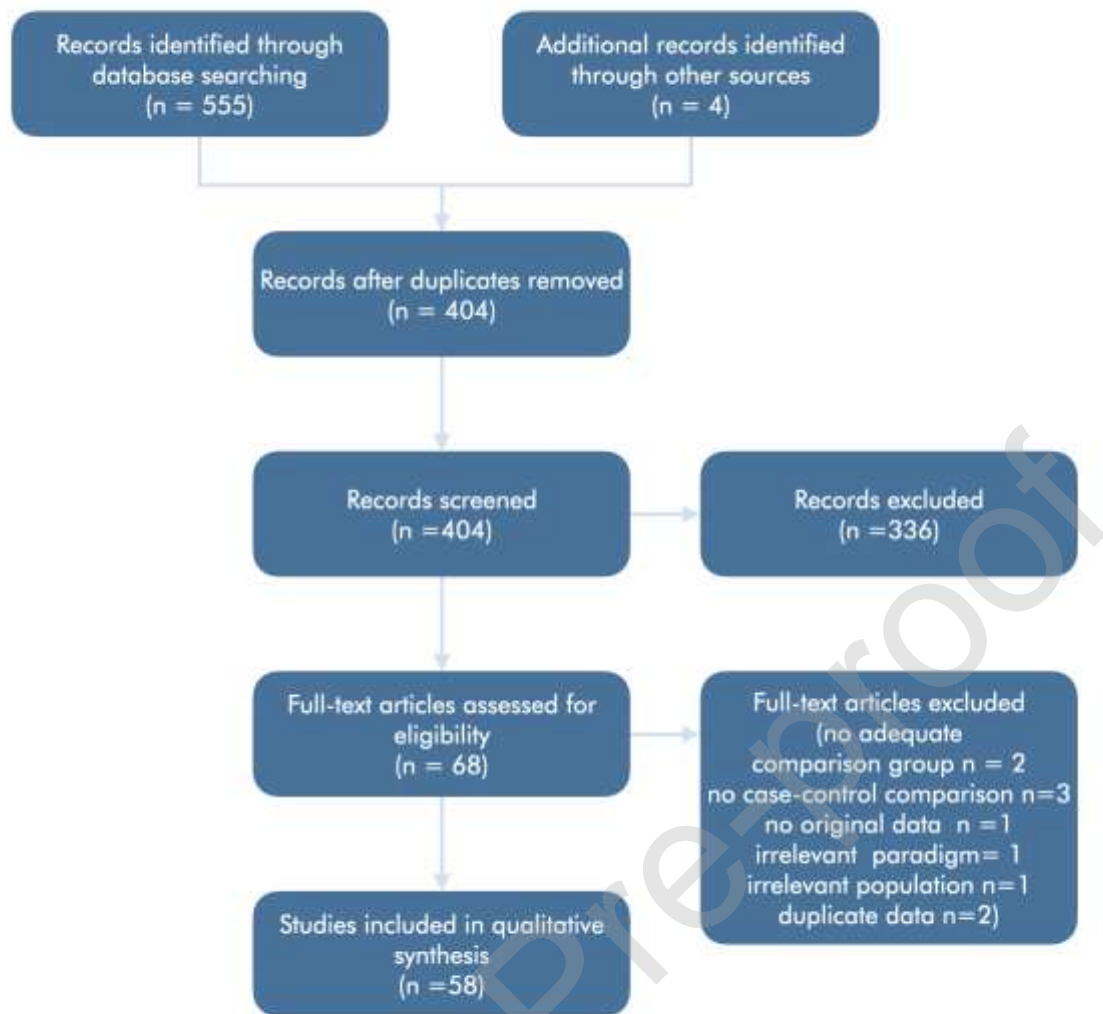


Figure 1. *Study selection process.*

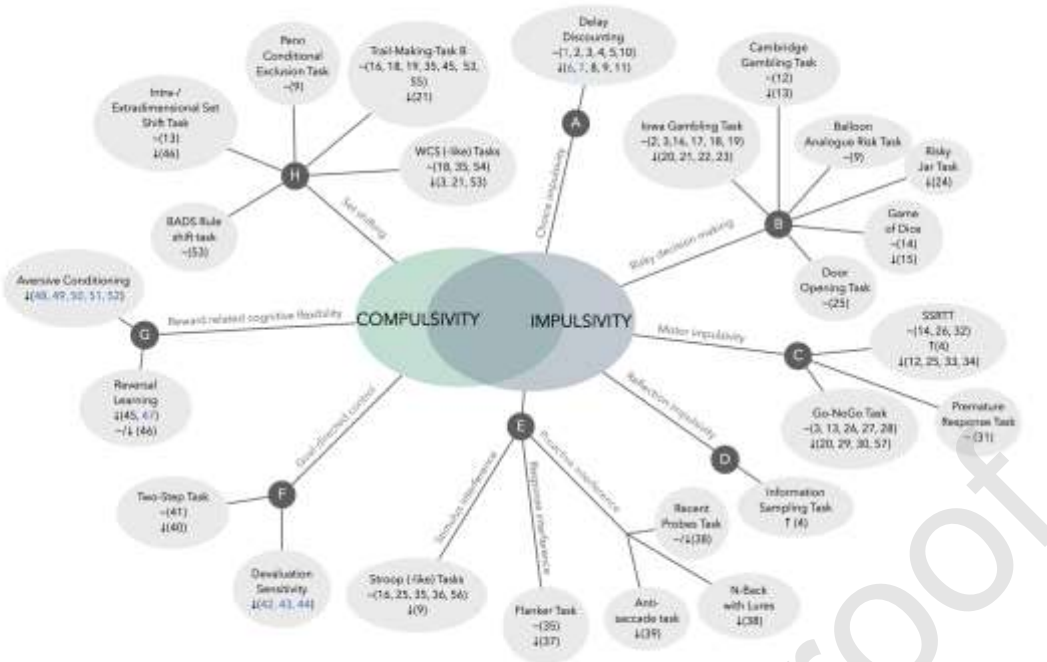


Figure 2. Overview of studies.

99, Animal study; ↑, Relatively improved performance in Binge Eating or Binge Eating Disorder (BED); ↓, Relatively impaired performance in BE(D); ~, No significant difference; ~ / ↓, Partial effect. Comparisons are between BE(D) and normal- or overweight/obese controls as reported in the respective studies. Where both comparisons were made, we show the comparison between BE(D) and overweight/obese participants. SSRT, Stop-Signal-Reaction-Time-Task; BADS, behavioral assessment of the dysexecutive syndrome; WCS, Wisconsin Card Sorting. **1** Moore, Blasio et al. (2018), **2** Davis, Patte et al. (2010), **3** Blume, Schmidt et al. (2019), **4** Mole, Irvine et al. (2015), **5** Yan, Zhang et al. (2018), **6** Vickers, Goddard et al. (2017), **7** Moore, Blasio et al. (2018), **8** Manwaring, Green et al. (2011), **9** Manasse, Forman et al. (2015), **10** Bartholdy, Rennalls et al. (2017a), **11** Steward, Mestre-Bach et al. (2017), **12** Grant & Chamberlain (2019), **13** Kollei, Rustemeier et al. (2018), **14** Wu, Giel et al. (2013), **15** Svaldi, Brand et al. (2010), **16** Kittel, Schmidt et al. (2017), **17** Danner, Ouwehand et al. (2012), **18** Dingemans, Vanhaelen et al. (2019), **19** Aloï, Rania et al. (2020), **20** Cordova, Schiavon et al. (2017), **21** Aloï, Rania et al. (2015), **22** Müller, Brandl et al. (2014), **23** Danner, Evers et al. (2013), **24** Voon, Morris et al. (2014), **25** Preuss, Leister et al. (2019), **26** Oliva, Morys et al. (2019), **27** Antunes, Elkfury et al. (2020), **28** Loeber, Rustemeier et al. (2018), **29** Hege, Stingl et al. (2015), **30** Lyu, Zheng et al. (2017), **31** Voon, Irvine et al. (2014), **32** Bartholdy, Rennalls et al. (2017b), **33** Svaldi, Naumann et al. (2014), **34** Manasse, Goldstein et al. (2016), **35** Eneva, Arlt et al. (2017), **36** Lee, Namkoong et al. (2017), **37** Lyu, Zheng et al. (2018), **38** Svaldi, Schmitz et al. (2014), **39** Schag, Teufel et al. (2013), **40** Voon, Derbyshire et al. (2015), **41** Voon, Joutsa et al. (2020), **42** LeMon, Sisk et al. (2019), **43** Furlong, Jayaweera et al. (2014), **44** Parkes, Furlong et al. (2017), **45** Reiter, Heinze et al. (2017), **46** Banca, Harrison et al. (2016), **47** Chawla, Corder et al. (2017), **48** Rossetti, Spena et al. (2013), **49** Moshe,

Bekker et al. (2017), **50** Oswald, Murdaugh et al. (2011), **51** Velázquez-Sánchez, Santos et al. (2015), **52** Heal, Goddard et al. (2016), **53** Duchesne, Mattos et al. (2010), **54** Kelly, Bulik et al. (2013), **55** Galioto, Spitznagel et al. (2012), **56** Balodis, Molina et al. (2013), **57** Mobbs, Iglesias et al. (2011).

Table 1. Characteristics of studies investigating choice impulsivity/delay and probability discounting in humans (A) and animals (B).

| A | Authors               | Year | Group   | Ascertainment | N  | BMI (M±SD) | Age (M±SD)  | Gender | Paradigm                                 | Main Finding                      | NOS Score |
|---|-----------------------|------|---------|---------------|----|------------|-------------|--------|--|-----------------------------------|-----------|
|   | Manwaring et al.      | 2011 | BED     | ★             | 30 | 42.0 ± 9.2 | 49.5 ± 9.6  | ♀      | Delay and probabilistic discounting task | BED>OW=/ $\gt$ NW                 | 6         |
|   |                       |      | OW      |               | 30 | 42.6 ± 7.9 | 48.8 ± 9.6  |        |  |                                   |           |
|   |                       |      | NW      |               | 30 | 23.3 ± 2.4 | 43.8 ± 12.4 |        |  |                                   |           |
|   | Davis, Patte et al.   | 2010 | BED     | ♣□            | 65 | 35.7 ± 9.0 | 34.3 ± 6.5  | ♀      | Delay Discounting Task                   | BED>NW, BED=OW                    | 5         |
|   |                       |      | OW      |               | 73 | 38.6 ± 7.2 | 35.2 ± 6.7  |        |  |                                   |           |
|   |                       |      | NW      |               | 71 | 21.7 ± 1.9 | 31.8 ± 6.3  |        |  |                                   |           |
|   | Blume, Schmidt et al. | 2019 | BED FA- | ★             | 19 | 41.9 ± 5.3 | 38.8 ± 9.4  | ♂      | Delay Discounting Task                   | OW(FA+)>BED(FA+)=BED(FA-)=OW(FA-) | 5         |

|                                      |      |            |    |    |               |                |   |  |            |  |   |
|--------------------------------------|------|------------|----|----|---------------|----------------|---|--|------------|--|---|
|                                      |      | BED<br>FA+ |    | 23 | 42.2 ±<br>6.1 | 37.5 ±<br>10.1 |   |  |            |  |   |
|                                      |      | OW<br>FA-  |    | 23 | 42.8 ±<br>4.8 | 40.5 ±<br>10.9 |   |  |            |  |   |
|                                      |      | OW<br>FA+  |    | 23 | 44.1 ±<br>6.6 | 43.4 ±<br>10.4 |   |  |            |  |   |
| Manasse<br>, Forman<br>et al.        | 2015 | BED        | ★  | 31 | 36.8 ±<br>8.0 | 45.1 ±<br>14.9 | ♀ | Delay<br>Discountin<br>g Task                | BED>OW     |  | 6 |
|                                      |      | OW         |    | 43 | 37.9 ±<br>6.3 | 51.1 ±<br>8.3  |   |  |            |  |   |
| Barthold<br>y,<br>Rennalls<br>et al. | 2017 | BED        |    | 11 | 28.9 ±<br>6.9 | 28.7 ±<br>11.2 | ♀ | Monetary<br>Temporal<br>Discountin<br>g Task | BED=NW     |  | 6 |
|                                      |      | NW         |    | 28 | 22.0 ±<br>2.0 | 24.6 ±<br>5.1  |   |  |            |  |   |
| Steward,<br>Mestre-<br>Bach et<br>al | 2017 | BED        | ♠□ | 24 | 38.9 ±<br>9.7 | 33.6 ±<br>8.6  | ♀ | Monetary<br>Choice<br>Questionn<br>aire      | BED>NW     |  | 4 |
|                                      |      | NW         |    | 80 | 21.6 ±<br>3.2 | 23.0 ±<br>4.4  |   |  |            |  |   |
| Mole,<br>Irvine et<br>al             | 2015 | BED        | ♣□ | 30 | 34.7 ±<br>5.5 | 42.9 ±<br>6.6  | ♂ | Monetary<br>Choice<br>Questionn<br>aire      | BED, OW>NW |  | 4 |
|                                      |      | OW         |    | 30 | 32.7 ±<br>3.4 | 44.1 ±<br>9.7  |   |  |            |  |   |
|                                      |      | NW         |    | 30 | 23.9 ±<br>2.7 | 44.0 ±<br>10.9 |   |  |            |  |   |



|                   |      |    |    |    |            |            |   |  |       |   |
|-------------------|------|----|----|----|------------|------------|---|--|-------|---|
| Yan, Zhang et al. | 2018 | BE | ◆□ | 85 | 21.0 ± 2.6 | 18.8 ± 0.9 | ♂ | Monetary Choice Questionnaire & Probabilistic discounting task | BE=NW | 6 |
|                   |      | NW |    | 92 | 20.7 ± 3.2 | 18.9 ± 0.8 |   |  |       |   |

| B | Authors                 | Year | Group | N  | Species | Sex | Paradigm               | Main Finding |
|---|-------------------------|------|-------|----|---------|-----|------------------------|--------------|
|   | Cano, Murphy et al.     | 2016 | BEP   | 6  | Rats    | ♂   | Delay discounting task | BEP>BER      |
|   |                         |      | BER   | 6  |         |     |                        |              |
|   | Vickers, Goddard et al. | 2017 | BE    | 12 | Rats    | ♀   | Delay discounting task | BE>CON       |
|   |                         |      | CON   | 6  |         |     |                        |              |
|   | Moore, Blasio et al.    | 2018 | BE    | 22 | Rats    | ♂   | Delay discounting task | BE=CON       |
|   |                         |      | CON   | 21 |         |     |                        |              |

BE(D) – Binge eating (disorder), OW – overweight/obese, NW – normal weight, FA – food addiction, BEP – binge eating prone, BER – binge eating resistant, CON – control, ★ – Eating disorder examination interview, ♣ – structured clinical

interview (SCID-IV, MINI, DIPS and/or MIDI), ♣ – clinical interview not otherwise specified, ♦ – Self-report (EDE-Q, EDDS, BES, EAT26), NOS – Newcastle-Ottawa Scale.

Table 2. Characteristics of studies investigating decision-making under risk/uncertainty in humans

| A . | Authors                   | Year | Group | Ascertainment | N  | BMI (M±SD) | Age (M±SD)  | Gender | Paradigm                     | Main Finding   | NOS Score |
|-----|---------------------------|------|-------|---------------|----|------------|-------------|--------|------------------------------|--|-----------|
|     | Manasse, Forman et al.    | 2015 | BED   | ★             | 31 | 36.8 ± 8.0 | 45.1 ± 14.9 | ♀      | Balloon Analogue Risk Task   | BED=OW   | 6         |
|     |                           |      | OW    |               | 43 | 37.9 ± 6.3 | 51.1 ± 8.3  |        |                              |  |           |
|     | Danner, Evers et al.      | 2013 | BED   | ♣ □           | 31 | 37.5 ± 5.1 | 38.5 ± 10.7 | ♀      | Iowa Gambling Task (adapted) | BED>NW<br>disadvantageous decks after<br>punishments & after<br>negative mood<br>induction | 3         |
|     |                           |      | NW    |               | 34 | 21.8 ± 2.3 | 30.2 ± 14.5 |        |                              |  |           |
|     | Kollej, Rustemeier et al. | 2018 | BED   | ♣ □           | 48 | 43.3 ± 6.3 | 40.7 ± 12.9 | ♂      | Cambridge Gambling Task      | BED=NW<OW risk<br>taking<br>BED=OW>delay<br>aversion,<br>deliberation time                 | 6         |
|     |                           |      | OW    |               | 48 | 43.6 ± 7.2 | 37.9 ± 12.7 |        |                              |  |           |
|     |                           |      | NW    |               | 48 | 22.1 ± 1.9 | 37.7 ± 15.7 |        |                              |  |           |
|     | Grant & Chamberlain       | 2019 | BED   | ♣ □           | 17 | 33.9 ± 5.1 | 25.5 ± 4.8  | ♂      | Cambridge Gambling Task      | BED=OW=NW  | 6         |

|                        |      |       |    |        |              |             |   |                    |                   |       |   |
|------------------------|------|-------|----|--------|--------------|-------------|---|--------------------|-------------------|-------|---|
|                        |      | OW    |    | 1<br>7 | 31.4 ± 6.3   | 23.8 ± 4.1  |   |                    |                   |       |   |
| Preuss et al.          | 2019 | BED   | ★  | 2<br>4 | 32.2 ± 4.5   | 37.4 ± 12.1 | ♂ | Door Opening Task  | BED=OW=NW         |       | 6 |
|                        |      | OW    |    | 4<br>7 | 33.5 ± 3.6   | 38.1 ± 10.0 |   |                    |                   |       |   |
|                        |      | NW    |    | 3<br>0 | 24.0 ± 2.5   | 36.3 ± 12.1 |   |                    |                   |       |   |
| Wu, Giel et al.        | 2013 | BED   | ♠□ | 5<br>4 | 34.0 ± 5.0   | 40.1 ± 11.6 | ♂ | Game of Dice       | BED=OW            |       | 6 |
|                        |      | OW    |    | 4<br>3 | 35.1 ± 5.1   | 39.8 ± 11.3 |   |                    |                   |       |   |
| Svaldi, Brand et al.   | 2010 | BED   | ★  | 1<br>7 | 32.8 ± 3.5   | 42.4 ± 12.3 | ♀ | Game of Dice       | BED>OW choices    | risky | 6 |
|                        |      | OW    |    | 1<br>8 | 30.7 ± 3.9   | 38.3 ± 13.1 |   |                    |                   |       |   |
| Davis, Patte et al.    | 2010 | BED   | ♣□ | 6<br>5 | 35.7 ± 9.0   | 34.3 ± 6.5  | ♀ | Iowa Gambling Task | BED=OW>NW choices | risky | 5 |
|                        |      | OW    |    | 7<br>3 | 38.6 ± 7.2   | 35.2 ± 6.7  |   |                    |                   |       |   |
|                        |      | NW    |    | 7<br>1 | 21.7 ± 1.9   | 31.8 ± 6.3  |   |                    |                   |       |   |
| Kittel, Schmidt et al. | 2017 | BE(D) | ★  | 2<br>2 | 99.2nd ± 0.6 | 14.9 ± 2.2  | ♂ | Iowa Gambling Task | BE(D)=OW=NW       |       | 6 |
|                        |      | OW    |    | 2<br>2 | 98.9th ± 2.3 | 14.8 ± 2.6  |   |                    |                   |       |   |

|                                       |      |                 |    |   |        |        |   |                          |                            |  |   |  |
|---------------------------------------|------|-----------------|----|---|--------|--------|---|--------------------------|----------------------------|--|---|--|
|                                       |      | NW              |    | 2 | 58.9th | 15.2 ± |   |                          |                            |  |   |  |
|                                       |      |                 |    | 2 | ± 24.0 | 2.4    |   |                          |                            |  |   |  |
| Cordova,<br>Schiavon et<br>al.        | 2017 | BE              | ◆□ | 1 | 37.3 ± | 40.7 ± | ♂ | Iowa<br>Gambling<br>Task | BE<OW<br>performance       |  | 3 |  |
|                                       |      |                 |    | 8 | 6.1    | 17.4   |   |                          |                            |  |   |  |
|                                       |      | OW              |    | 1 | 39.8 ± | 49.5 ± |   |                          |                            |  |   |  |
|                                       |      |                 |    | 8 | 8.6    | 14.8   |   |                          |                            |  |   |  |
| Aloi, Rania<br>et al.                 | 2015 | BED             | ♠□ | 4 | 35.2 ± | 30.6 ± | ♀ | Iowa<br>Gambling<br>Task | BED<NW<br>performance      |  | 6 |  |
|                                       |      |                 |    | 5 | 6.5    | 10.9   |   |                          |                            |  |   |  |
|                                       |      | NW              |    | 4 | 20.2 ± | 25.6 ± |   |                          |                            |  |   |  |
|                                       |      |                 |    | 5 | 1.6    | 3.5    |   |                          |                            |  |   |  |
| Müller,<br>Brandl et<br>al.           | 2014 | BED             | ◆□ | 3 | 46.7 ± | 38.2 ± | ♂ | Iowa<br>Gambling<br>Task | BE<OW<br>performance       |  | 5 |  |
|                                       |      |                 |    | 4 | 9.0    | 12.0   |   |                          |                            |  |   |  |
|                                       |      | OW              |    | 3 | 46.6 ± | 38.5 ± |   |                          |                            |  |   |  |
|                                       |      |                 |    | 4 | 7.7    | 11.9   |   |                          |                            |  |   |  |
| Danner,<br>Ouwehand<br>et al.         | 2012 | BED             | ♣□ | 2 | 38.5 ± | 38.1 ± | ♀ | Iowa<br>Gambling<br>Task | BED=OW<NW<br>performance   |  | 3 |  |
|                                       |      |                 |    | 0 | 6.3    | 11.0   |   |                          |                            |  |   |  |
|                                       |      | OW              |    | 2 | 30.8 ± | 44.6   |   |                          |                            |  |   |  |
|                                       |      |                 |    | 1 | 3.0    | ±13.4  |   |                          |                            |  |   |  |
|                                       |      | NW              |    | 3 | 22.3 ± | 36.1 ± |   |                          |                            |  |   |  |
|                                       |      |                 |    | 4 | 2.0    | 14.1   |   |                          |                            |  |   |  |
| Dingemans<br>,<br>Vanhaelen<br>et al. | 2019 | BED<br>DEP-     | ★  | 2 | 38.5 ± | 32.8 ± | ♂ | Iowa<br>Gambling<br>Task | BED(DEP+)=BED(D<br>EP-)=NW |  | 6 |  |
|                                       |      |                 |    | 5 | 7.4    | 8.5    |   |                          |                            |  |   |  |
|                                       |      | BED<br>DEP<br>+ |    | 6 | 37.6 ± | 34.2 ± |   |                          |                            |  |   |  |
|                                       |      |                 |    | 6 | 6.2    | 9.9    |   |                          |                            |  |   |  |

|                             |      |            |    |        |               |                |   |                          |   |   |
|-----------------------------|------|------------|----|--------|---------------|----------------|---|--------------------------|---|---|
|                             |      | NW         |    | 5      | 23.5 ±        | 36.7 ±         |   |                          |   |   |
|                             |      |            |    | 6      | 2.8           | 12.3           |   |                          |   |   |
| Blume,<br>Schmidt et<br>al. | 2019 | BED<br>FA- | ★  | 1<br>9 | 41.9 ±<br>5.3 | 38.8 ±<br>9.4  | ∅ | Iowa<br>Gambling<br>Task | BED(FA+)=BED(FA-)<br>)=OW(FA+)=OW(F<br>A-)                                    | 5 |
|                             |      | BED<br>FA+ |    | 2<br>3 | 42.2 ±<br>6.1 | 37.5 ±<br>10.1 |   |                          |   |   |
|                             |      | OW<br>FA-  |    | 2<br>3 | 42.8 ±<br>4.8 | 40.5 ±<br>10.9 |   |                          |   |   |
|                             |      | OW<br>FA+  |    | 2<br>3 | 44.1 ±<br>6.6 | 43.4 ±<br>10.4 |   |                          |   |   |
| Aloi, Rania<br>et al.       | 2020 | BED        | ♣□ | 3<br>5 | 38.9 ±<br>6.9 | 44.2 ±<br>10.7 | ∅ | Iowa<br>Gambling<br>Task | BED=OW<NW<br>performance  | 5 |
|                             |      | OW         |    | 3<br>2 | 36.4 ±<br>6.8 | 49.6 ±<br>9.9  |   |                          |   |   |
|                             |      | NW         |    | 2<br>6 | 23.0 ±<br>0.8 | 46.7 ±<br>11.1 |   |                          |   |   |
| Voon,<br>Morris et<br>al.   | 2014 | BED        | ♣□ | 3<br>0 | 34.7 ±<br>5.5 | 42.9 ±<br>6.6  | ∅ | Risky Jar<br>Task        | BED>NW<br>overweighting of<br>probabilities<br>BED>NW risk taking<br>(reward) | 5 |
|                             |      | OW         |    | 3<br>0 | 32.7 ±<br>3.4 | 44.1 ±<br>9.7  |   |                          |   |   |
|                             |      | NW         |    | 3<br>0 | 23.0 ±<br>2.7 | 44.0 ±<br>10.9 |   |                          |   |   |

BE(D) – Binge eating (disorder), OW – overweight/obese, NW – normal weight, FA – food addiction, DEP – depression, ★ – Eating disorder examination interview, ♠ – structured clinical interview (SCID-IV, MINI, DIPS and/or MIDI), ♣ – clinical interview not otherwise specified, ♦ – Self-report (EDE-Q, EDDS, BES, EAT26), NOS – Newcastle-Ottawa Scale, BMI summary statistics for Kittel, Schmidt et al. (2017) are in percentiles.

Table 3. Characteristics of studies investigating motor impulsivity in humans.

| A | Authors                  | Year | Group      | Ascertainment | N  | BMI (M±SD) | Age (M±SD)  | Gender | Paradigm                                      | Main Finding                            | NOS Score |
|---|--------------------------|------|------------|---------------|----|------------|-------------|--------|---|---|-----------|
| . | Mobbs, Iglesias et al.   | 2011 | BED        | ♣□            | 16 | 34.6 ± 3.5 | 45.1 ± 12.1 | ♀      | Food-Body Mental Flexibility Task             | BED>OW>N<br>W commission errors         | 5         |
|   |                          |      | OW         |               | 16 | 33.6 ± 6.4 | 39.3 ± 12.2 |        |   | BED>OW>N<br>W omissions (food context)  |           |
|   |                          |      | NW         |               | 16 | 21.3 ± 1.8 | 40.2 ± 11.3 |        |   | BED=OW>N<br>W omissions (other stimuli) |           |
| . | Cordova, Schiavon et al. | 2017 | BED        | ♦□            | 18 | 37.3 ± 6.1 | 40.7 ± 17.4 | ♂      | Go-NoGo Task                                  | BED>OW<br>commission errors             | 3         |
|   |                          |      | OW         |               | 18 | 39.8 ± 8.6 | 49.5 ± 14.8 |        |   | BED=OW<br>omissions                     |           |
| . | Blume, Schmidt et al.    | 2019 | BED<br>FA- | ★             | 19 | 41.9 ± 5.3 | 38.8 ± 9.4  | ♀      | BED(FA+)=BED(FA-)=OW(FA+)=OW(FA-) commissions |   | 5         |
|   |                          |      | BED<br>FA+ |               | 23 | 42.2 ± 6.1 | 37.5 ± 10.1 |        |   |   |           |
|   |                          |      | OW<br>FA-  |               | 23 | 42.8 ± 4.8 | 40.5 ± 10.9 |        |   |   |           |
|   |                          |      | OW<br>FA+  |               | 23 | 44.1 ± 6.6 | 43.4 ± 10.4 |        |   |   |           |

|                                  |      |     |    |        |            |             |   |                             |  |   |
|----------------------------------|------|-----|----|--------|------------|-------------|---|-----------------------------|--|---|
| Oliva, Morys et al.              | 2019 | BE  | ◆□ | 2<br>1 | 22.3 ± 2.1 | 23.9 ± 3.2  | ♂ | Go-NoGo (food and non food) | Task BE=NW   | 5 |
|                                  |      | NW  |    | 2<br>1 | 21.3 ± 2.0 | 25.2 ± 3.1  |   |                             |  |   |
| Antunes, Lorenzzi Elkfury et al. | 2020 | BED | ♠□ | 1<br>3 | 33.2 ± 3.7 | 26.4 ± 4.3  | ♀ | Go-NoGo (food and non food) | Task BED=OW=N W comission errors (food and non-food) | 5 |
|                                  |      | OW  |    | 2<br>0 | 33.1 ± 4.0 | 31.0 ± 7.3  |   |                             |  |   |
|                                  |      | NW  |    | 1<br>4 | 21.3 ± 2.0 | 32.2 ± 7.9  |   |                             |  |   |
| Loeber, Rustemeier et al.        | 2018 | BED | ♣□ | 1<br>7 | 39.3 ± 6.0 | 26.5 ± 3.5  | ♀ | Go-NoGo (food and non food) | Task BED=OW=N W comission errors                     | 6 |
|                                  |      | OW  |    | 2<br>0 | 33.2 ± 3.2 | 25.0 ± 5.2  |   |                             |  |   |
|                                  |      | NW  |    | 2<br>0 | 22.5 ± 2.1 | 23.6 ± 2.0  |   |                             |  |   |
| Hege, Stingl et al.              | 2015 | BED | ♠□ | 1<br>7 | 36.5 ± 4.9 | 41.4 ± 12.3 | ♀ | Go-NoGo (food and non food) | Task BED<OW performance NoGo trials (food condition) | 5 |
|                                  |      | OW  |    | 1<br>7 | 34.0 ± 5.6 | 41.9 ± 8.5  |   |                             |  |   |
| Kollej, Rustemeier et al.        | 2018 | BED | ♠□ | 4<br>8 | 43.3 ± 6.3 | 40.7 ± 12.9 | ♂ | Go-NoGo (food)              | Task BED=OW=N W                                      | 6 |
|                                  |      | OW  |    | 4<br>8 | 43.6 ± 7.2 | 37.9 ± 12.7 |   |                             |  |   |
|                                  |      | NW  |    | 4<br>8 | 22.1 ± 1.9 | 37.7 ± 15.7 |   |                             |  |   |

|                     |      |     |    |   |            |             |   |                         |        |  |   |
|---------------------|------|-----|----|---|------------|-------------|---|-------------------------|--------|--|---|
| Lyu, Zheng et al.   | 2017 | BE  | ◆□ | 3 | 20.5 ± 2.2 | 21.5 ± 1.4  | ♀ | Go-NoGo (food)          | Task   | BE<NW performance high calorie Go trials | 5 |
|                     |      | NW  |    | 3 | 19.6 ± 2.1 | 21.4 ± 1.5  |   |                         |        |  |   |
| Voon, Irvine et al. | 2014 | BED | ♣□ | 3 | 34.7 ± 5.5 | 42.9 ± 6.6  | ♂ | Premature Response Task | Signal | BED=OW=NW                                | 5 |
|                     |      | OW  |    | 3 | 32.7 ± 3.4 | 44.1 ± 9.7  |   |                         |        |  |   |
|                     |      | NW  |    | 3 | 23.0 ± 2.7 | 44.0 ± 10.9 |   |                         |        |  |   |
| Wu, Giel et al.     | 2013 | BED | ♠□ | 5 | 34.0 ± 5.0 | 40.1 ± 11.6 | ♂ | Stop Reaction Time Task | Signal | BED=OW                                   | 6 |
|                     |      | OW  |    | 4 | 35.1 ± 5.1 | 39.8 ± 11.3 |   |                         |        |  |   |
| Mole, Irvine et al. | 2014 | BED | ♣□ | 3 | 34.7 ± 5.5 | 42.9 ± 6.6  | ♂ | Stop Reaction Time Task | Signal | BED=NW<OW SSRT                           | 4 |
|                     |      | OW  |    | 3 | 32.7 ± 3.4 | 44.1 ± 9.7  |   |                         |        |  |   |
|                     |      | NW  |    | 3 | 23.9 ± 2.7 | 44.0 ± 10.9 |   |                         |        |  |   |
| Preuss et al.       | 2019 | BED | ★  | 2 | 32.2 ± 4.5 | 37.4 ± 12.1 | ♂ | Stop Reaction Time Task | Signal | BED>NW=OW SSRT                           | 6 |
|                     |      | OW  |    | 4 | 33.5 ± 3.6 | 38.1 ± 10.0 |   |                         |        |  |   |
|                     |      | NW  |    | 3 | 24.0 ± 2.5 | 36.3 ± 12.1 |   |                         |        |  |   |



|                                 |     |    |        |            |             |   |   |               |                         |   |
|---------------------------------|-----|----|--------|------------|-------------|---|---|---------------|-------------------------|---|
| Grant & Chamberlain 2019        | BED | ♠□ | 1<br>7 | 33.9 ± 5.1 | 25.5 ± 4.8  | ♂ | Stop Reaction Time Task                     | Signal W SSRT | BED>NW=0                | 6 |
|                                 | OW  |    | 1<br>7 | 31.4 ± 6.3 | 23.8 ± 4.1  |   |   |               |                         |   |
| Bartholdy, Rennalls et al. 2017 | BED | ♠□ | 1<br>1 | 28.9 ± 6.9 | 28.7 ± 11.2 | ♀ | Stop Reaction Time Task                     | Signal        | BED=NW                  | 6 |
|                                 | NW  |    | 2<br>8 | 22.0 ± 2.0 | 24.6 ± 5.1  |   |   |               |                         |   |
| Oliva, Morys et al. 2019        | BE  | ♦□ | 2<br>1 | 22.3 ± 2.1 | 23.9 ± 3.2  | ♂ | Stop Reaction Time Task (food and non-food) | Signal        | BE=NW commission errors | 5 |
|                                 | NW  |    | 2<br>1 | 21.3 ± 2.0 | 25.2 ± 3.1  |   |   |               |                         |   |
| Svaldi, Naumann et al. 2014     | BED | ★  | 3<br>1 | 35.0 ± 5.1 | 45.5 ± 12.8 | ♂ | Stop Reaction Time Task (food and non-food) | Signal        | BED>OW SSRT             | 6 |
|                                 | OW  |    | 2<br>9 | 32.0 ± 6.0 | 40.1 ± 12.1 |   |   |               |                         |   |
| Manasse, Goldstein et al. 2016  | BED | ★  | 2<br>5 | 35.2 ± 7.7 | 45.1 ± 14.9 | ♀ | Stop Reaction Time Task (food and non-food) | Signal        | BED>OW SSRT             | 5 |
|                                 | OW  |    | 6<br>5 | 36.7 ± 5.5 | 52.4 ± 9.2  |   |   |               |                         |   |

BE(D) – Binge eating (disorder), OW – overweight/obese, NW – normal weight, FA – food addiction, ★ – Eating disorder examination interview, ♠ – structured clinical interview (SCID-IV, MINI, DIPS and/or MIDI), ♠ – clinical interview not otherwise specified, ♦ – Self-report (EDE-Q, EDDS, BES, EAT26), NOS – Newcastle-Ottawa Scale.

Table 4. Characteristics of studies investigating reflection impulsivity in humans.

| A. | Authors            | Year | Group | Ascertainment | N  | BMI (M±SD) | Age (M±SD)  | Gender | Paradigm                  | Main Finding  | NOS Score |
|----|--------------------|------|-------|---------------|----|------------|-------------|--------|---------------------------|---|-----------|
|    | Mole, Irvine et al | 2014 | BED   | ♣□            | 30 | 34.7 ± 5.5 | 42.9 ± 6.6  | ♂      | Information Sampling Task | BED=NW>OW<br>total points<br>BED=NW<OW<br>sampling errors | 4         |
|    |                    |      | OW    |               | 30 | 32.7 ± 3.4 | 44.1 ± 9.7  |        |                           |   |           |
|    |                    |      | NW    |               | 30 | 23.9 ± 2.7 | 44.0 ± 10.9 |        |                           |   |           |

BE(D) – Binge eating (disorder), OW – overweight/obese, NW – normal weight, ♣ – clinical interview not otherwise specified, NOS – Newcastle-Ottawa Scale.

Table 5. Characteristics of studies investigating interference control in humans.

| A. | Authors              | Year | Group | Ascertainment | N      | BMI (M±SD) | Age (M±SD)  | Gender | Paradigm          | Main Finding  | NOS Score |
|----|----------------------|------|-------|---------------|--------|------------|-------------|--------|-------------------|---|-----------|
|    | Schag, Teufel et al. | 2013 | BE(D) | ♣□            | 2<br>5 | 35.4 ± 5.6 | 39.7 ± 11.7 | ♀      | Anti saccade task |   | 5         |
|    |                      |      | OW    |               | 2<br>6 | 35.4 ± 5.4 | 39.9 ± 12.6 |        |                   | BE(D)>OW=NW<br>disengagement (overall),<br>particularly food on<br>second saccade |           |
|    |                      |      | NW    |               | 2<br>5 | 22.5 ± 1.6 | 39.4 ± 11.8 |        |                   |   |           |

|                               |      |           |    |        |                  |             |   |   |   |    |   |
|-------------------------------|------|-----------|----|--------|------------------|-------------|---|---|---|----|---|
| Kittel,<br>Schmidt<br>et al.  | 2017 | BE(D)     | ★  | 2<br>2 | 99.2nd<br>± 0.6  | 14.9 ± 2.2  | ♂ | Colour-<br>Word-<br>Interferen-<br>ce Test                  | BE(D)=OW>NW<br>completion time  | 6  |   |
|                               |      | OW        |    | 2<br>2 | 98.9th<br>± 2.3  | 14.8 ± 2.6  |   |   |   |    |   |
|                               |      | NW        |    | 2<br>2 | 58.9th<br>± 24.0 | 15.2 ± 2.4  |   |   |   |    |   |
| Eneva et<br>al.               | 2017 | BED<br>OW | ★  | 3<br>2 | 34.2 ± 0.8       | 36.3 ± 2.0  | ♀ | D-KEFS<br>Colour<br>Word<br>Interferen-<br>ce<br>inhibition | BED(OW)=BED(NW)=O<br>W=NW   | 6  |   |
|                               |      | BED<br>NW |    | 2<br>3 | 22.9 ± 0.4       | 23.3 ± 0.7  |   |   |   |    |   |
|                               |      | OW        |    | 4<br>8 | 31.3 ± 0.6       | 38.0 ± 1.8  |   |   |   |    |   |
|                               |      | NW        |    | 2<br>9 | 21.6 ± 0.3       | 24.5 ± 1.2  |   |   |   |    |   |
| Manasse<br>, Forman<br>et al. | 2015 | BED       | ★  | 3<br>1 | 36.8 ± 8.0       | 45.1 ± 14.9 | ♀ | D-KEFS<br>Colour<br>Word<br>Interferen-<br>ce<br>inhibition | BED>OW<br>BED=OW errors   | RT | 6 |
|                               |      | OW        |    | 4<br>3 | 37.9 ± 6.3       | 51.1 ± 8.3  |   |   |   |    |   |
| Lyu,<br>Zheng et<br>al.       | 2018 | BE        | ◆□ | 3<br>1 | 21.0 ± 0.5       | 20.0 ± 0.7  | ♀ | Flanker<br>Task<br>(Food)                                   | BE > NW Flanker effect on<br>RT<br>NW > BE RT for low calorie<br>food | 5  |   |
|                               |      | NW        |    | 3<br>3 | 20.4 ± 0.4       | 21.2 ± 0.3  |   |   |   |    |   |
| Balodis,<br>Molina<br>et al.  | 2013 | BED       | ♠□ | 1<br>1 | 37.1 ± 3.9       | 47.6 ± 12.7 | ♂ | Stroop<br>Task  | BED=OW=NW<br>performance  | 5  |   |

|                        |      |     |    |        |               |                |   |                                |   |       |
|------------------------|------|-----|----|--------|---------------|----------------|---|--------------------------------|---|-------|
|                        |      | OW  |    | 1<br>3 | 34.6 ±<br>4.1 | 35.4 ±<br>9.3  |   |                                |   |       |
|                        |      | NW  |    | 1<br>1 | 23.2<br>±1.1  | 32.7 ±<br>11.3 |   |                                |   |       |
| Preuss et al.          | 2019 | BED | ★  | 2<br>4 | 32.2 ±<br>4.5 | 37.4 ±<br>12.1 | ♀ | Stroop Task (Food)             | BED=OW=NW interference index            | RT, 6 |
|                        |      | OW  |    | 4<br>7 | 33.5 ±<br>3.6 | 38.1 ±<br>10.0 |   |                                |   |       |
|                        |      | NW  |    | 3<br>0 | 24.0 ±<br>2.5 | 36.3 ±<br>12.1 |   |                                |   |       |
| Lee, Namkoo ng et al.  | 2017 | BED | ♠□ | 1<br>3 | 25.6 ±<br>3.8 | 23.6 ±<br>2.6  | ♀ | Stroop Match to Sample (Food)  | BED=NW accuracy, RT                     | 5     |
|                        |      | NW  |    | 1<br>4 | 20.4 ±<br>2.6 | 23.3 ±<br>2.2  |   |                                |   |       |
| Svaldi, Schmitz et al. | 2014 | BED | ★  | 2<br>6 | 34.9 ±<br>5.4 | 46.1 ±<br>14.6 | ♀ | N-Back with lures              | BED>OW errors and RT during lure trials | 6     |
|                        |      | OW  |    | 3<br>1 | 33.6 ±<br>6.4 | 39.7 ±<br>11.9 |   |                                |   |       |
| Eneva et al.           | 2017 | BED | ★  | 3      | 34.2 ±        | 36.3 ±         | ♀ | NIH Flanker Inhibitory Control | BED(OW)=BED(NW)=0 W=NW                  | 6     |
|                        |      | OW  |    | 2      | 0.8           | 2.0            |   |                                |   |       |
|                        |      | BED |    | 2      | 22.9 ±        | 23.3 ±         |   |                                |   |       |
|                        |      | NW  |    | 3      | 0.4           | 0.7            |   |                                |   |       |
|                        |      | OW  |    | 4<br>8 | 31.3 ±<br>0.6 | 38.0 ±<br>1.8  |   |                                |   |       |

|                              |      |     |   |   |        |        |   |                          |  |  |   |
|------------------------------|------|-----|---|---|--------|--------|---|--------------------------|--|--|---|
|                              |      | NW  |   | 2 | 21.6 ± | 24.5 ± |   |                          |  |  |   |
|                              |      |     |   | 9 | 0.3    | 1.2    |   |                          |  |  |   |
| Svaldi,<br>Schmitz<br>et al. | 2014 | BED | ★ | 3 | 35.14  | 46.3 ± | ♀ | Recent<br>Probes<br>Task |  |  | 6 |
|                              |      | OW  |   | 3 | 33.31  | 40.7 ± |   |                          |  |  |   |
|                              |      |     |   | 6 | ± 6.2  | 13.1   |   |                          |  |  |   |

BED=OW/OB accuracy  
BED>OW/OB interference  
by food stimuli

BE(D) – Binge eating (disorder), OW – overweight/obese, NW – normal weight, FA – food addiction, ★ – Eating disorder examination interview, ♠ – structured clinical interview (SCID-IV, MINI, DIPS and/or MIDI), ♣ – clinical interview not otherwise specified, ♦ – Self-report (EDE-Q, EDSS, BES, EAT26), NOS – Newcastle-Ottawa Scale, BMI summary statistics for Kittel, Schmidt et al. (2017) are in percentiles.

Table 6. Characteristics of studies investigating goal directed and habitual control in humans (A) and animals (B).

| A | Authors                       | Year | Group | Ascertainment | N | BMI (M±SD) | Age (M±SD) | Gender | Paradigm         | Main Finding   | NOS Score |
|---|-------------------------------|------|-------|---------------|---|------------|------------|--------|------------------|--|-----------|
|   | Voon,<br>Derbyshire<br>et al. | 2015 | BED   | ♠□            | 3 | 35.0 ±     | 42.8 ±     | ♀      | Two Step<br>Task |  | 5         |
|   |                               |      | OW    |               | 3 | 31.5 ±     | 44.2 ±     |        |                  | BED<OW=N<br>W model<br>based control<br>BED>OW=N<br>W<br>perseveration |           |
|   |                               |      | NW    |               | 9 | 24.0 ±     | 42.7 ±     |        |                  |  |           |
|   |                               |      |       |               | 3 | 2.9        | 10.4       |        |                  |  |           |

|                |        |      |     |    |   |            |             |   |               |                            |   |
|----------------|--------|------|-----|----|---|------------|-------------|---|---------------|----------------------------|---|
| Voon, Joutsal. | et al. | 2020 | BED | ♠□ | 7 | 30.9 ± 6.6 | 49.4 ± 5.1  | ♂ | Two Step Task | BED=NW model based control | 4 |
|                |        |      | NW  |    | 1 | 24.8 ± 2.1 | 43.3 ± 11.1 |   |               | BED>NW perseveration       |   |

| B. Authors                | Year | Group | N | Species | Sex | Paradigm    | Main Finding                                    |
|---------------------------|------|-------|---|---------|-----|-------------|---|
| LeMon, Sisk et al.        | 2019 | BE    | 1 | Rats    | ♀   | Devaluation | BE>CON devaluation sensitivity (lever presses), |
|                           |      | CON   | 6 |         |     |             | BE=CON devaluation sensitivity (food choice)    |
| Furlong, Jayaweera et al. | 2014 | BE    | 1 | Rats    | ♂   | Devaluation | BE>CON devaluation sensitivity (lever presses)  |
|                           |      | CON   | 2 |         |     |             |   |
|                           |      |       | 4 |         |     |             |   |
| Parkes, Furlong et al.    | 2017 | BE    | 2 | Rats    | ♂   | Devaluation | BE>CON devaluation sensitivity (lever presses)  |
|                           |      | CON   | 2 |         |     |             |   |
|                           |      |       | 3 |         |     |             |   |

BE(D) – Binge eating (disorder), OW – overweight/obese, NW – normal weight, CON – control, ♠ – structured clinical interview (SCID-IV, MINI, DIPS and/or MIDI), NOS – Newcastle-Ottawa Scale.

Table 7. Characteristics of studies investigating cognitive flexibility in humans (A) and animals (B).

| A | Authors                 | Year | Group | Ascertainment | N  | BMI (M±SD)    | Age (M±SD) | Gender | Paradigm                                    | Main Finding          | NOS Score |
|---|-------------------------|------|-------|---------------|----|---------------|------------|--------|---|-----------------------|-----------|
|   | Duchesse, Mattos et al. | 2010 | BED   | ♠□            | 38 | 35.9 ± 2.9    | 33.3 ± 5.0 | ♀      | BADS-Rule Shift Cards Test                  | BED=OW                | 5         |
|   |                         |      | OW    |               | 38 | 36.6 ± 3.8    | 35.4 ± 7.9 |        |   |                       |           |
|   | Kittel, Schmidt et al.  | 2017 | BE(D) | ★             | 22 | 99.2nd ± 0.6  | 14.9 ± 2.2 | ♀      | Comprehensive Trail Making Test             | BE(D)=OW=NW           | 6         |
|   |                         |      | OW    |               | 22 | 98.9th ± 2.3  | 14.8 ± 2.6 |        |   |                       |           |
|   |                         |      | NW    |               | 22 | 58.9th ± 24.0 | 15.2 ± 2.4 |        |   |                       |           |
|   | Eneva et al.            | 2017 | BED   | ★             | 32 | 34.2 ± 0.8    | 36.3 ± 2.0 | ♀      | D-KEFS trail-making number-letter switching | BED(OW)=BED(NW)=OW=NW | 6         |
|   |                         |      | BED   |               | 23 | 22.9 ± 0.4    | 23.3 ± 0.7 |        |   |                       |           |
|   |                         |      | NW    |               | 33 | 31.3 ± 0.6    | 38.0 ± 1.8 |        |   |                       |           |
|   |                         |      | OW    |               | 48 | 21.6 ± 0.3    | 24.5 ± 1.2 |        |   |                       |           |

|                          |      |     |    |       |       |        |   |   |  |   |
|--------------------------|------|-----|----|-------|-------|--------|---|---|--|---|
| Eneva et al.             | 2017 | BED | ★  | 3     | 34.2  | 36.3   | ♀ | Dimensional Change Card Sort Test         | BED(OW)=BED(NW)=0<br>W=NW                | 6 |
|                          |      | OW  |    | 2     | ± 0.8 | ± 2.0  |   |   |  |   |
|                          |      | BED |    | 2     | 22.9  | 23.3   |   |   |  |   |
|                          |      | NW  | 3  | ± 0.4 | ± 0.7 |        |   |   |  |   |
|                          |      | OW  |    | 4     | 31.3  | 38.0   |   |   |  |   |
|                          |      |     |    | 8     | ± 0.6 | ± 1.8  |   |   |  |   |
|                          |      | NW  |    | 2     | 21.6  | 24.5   |   |   |  |   |
|                          |      |     |    | 9     | ± 0.3 | ± 1.2  |   |   |  |   |
| Kollei, Rustemier et al. | 2018 | BED | ♠□ | 4     | 43.3  | 40.7   | ♂ | Intra-/Extradimensional set shifting task | BED=NW=OW                                | 6 |
|                          |      | OW  |    | 8     | ± 6.3 | ± 12.9 |   |   |  |   |
|                          |      | OW  |    | 4     | 43.6  | 37.9   |   |   |  |   |
|                          |      |     |    | 8     | ± 7.2 | ± 12.7 |   |   |  |   |
|                          |      | NW  |    | 4     | 22.1  | 37.7   |   |   |  |   |
|                          |      |     |    | 8     | ± 1.9 | ± 15.7 |   |   |  |   |
| Banca, Harrison et al.   | 2016 | BED | ♠□ | 3     | 34.7  | 42.8   | ♂ | Intra-/Extradimensional set shifting task | BED>NW, OW=NW<br>extradimensional errors | 5 |
|                          |      | OW  |    | 2     | ± 5.6 | ± 8.6  |   |   |  |   |
|                          |      | OW  |    | 3     | 32.7  | 43.9   |   |   |  |   |
|                          |      |     |    | 1     | ± 3.4 | ± 9.6  |   |   |  |   |
|                          |      | NW  |    | 6     | 22.9  | 43.5   |   |   |  |   |
|                          |      |     |    | 4     | ± 2.9 | ± 10.9 |   |   |  |   |
| Manasse, Forman et al.   | 2015 | BED | ★  | 3     | 36.8  | 45.1   | ♀ | Penn Condition Exclusion Task             | BED=OW                                   | 6 |
|                          |      | OW  |    | 1     | ± 8.0 | ± 14.9 |   |   |  |   |
|                          |      | OW  |    | 4     | 37.9  | 51.1   |   |   |  |   |
|                          |      |     |    | 3     | ± 6.3 | ± 8.3  |   |   |  |   |



|                         |      |     |    |   |       |        |   |                                      |   |   |
|-------------------------|------|-----|----|---|-------|--------|---|--------------------------------------|---|---|
| Reiter, Heinze et al.   | 2017 | BED | ★  | 2 | 28.3  | 29.0   | ♂ | Probabilistic Reversal Learning Task | BED>NW switching performance<br>BED<NW stochasticity of choices   | 5 |
|                         |      | NW  |    | 2 | 26.1  | 27.8   |   |                                      |   |   |
|                         |      |     |    | 2 | ± 6.6 | ± 9.4  |   |                                      |   |   |
|                         |      |     |    | 2 | ± 4.4 | ± 4.5  |   |                                      |   |   |
| Banca, Harrison et al.  | 2016 | BED | ♠□ | 3 | 34.7  | 42.8   | ♂ | Probabilistic Reversal Learning Task | Reversal phase: BED=OW=NW overall in win condition<br>NW<BED in loss condition (trials to criterion)<br>NW>BED less shifting after losses in reversal compared to acquisition<br>BED>NW more shifting after wins in reversal compared to acquisition<br>BED>OW win stay across acquisition and reversal | 5 |
|                         |      | OW  |    | 3 | 32.7  | 43.9   |   |                                      |   |   |
|                         |      | NW  |    | 6 | 22.9  | 43.5   |   |                                      |   |   |
|                         |      |     |    | 2 | ± 5.6 | ± 8.6  |   |                                      |   |   |
|                         |      |     |    | 1 | ± 3.4 | ± 9.6  |   |                                      |   |   |
|                         |      |     |    | 4 | ± 2.9 | ± 10.9 |   |                                      |   |   |
| Aloi, Rania et al.      | 2015 | BED | ♠□ | 4 | 35.2  | 30.6   | ♀ | Trail Making Task B                  | BED>NW time, errors   | 6 |
|                         |      | NW  |    | 4 | 20.2  | 25.6   |   |                                      |   |   |
|                         |      |     |    | 5 | ± 6.5 | ± 10.9 |   |                                      |   |   |
|                         |      |     |    | 5 | ± 1.6 | ± 3.5  |   |                                      |   |   |
| Duchesne, Mattos et al. | 2010 | BED | ♠□ | 3 | 35.9  | 33.3   | ♂ | Trail Making Task B                  | BED=OW time   | 5 |
|                         |      | OW  |    | 3 | 36.6  | 35.4   |   |                                      |   |   |
|                         |      |     |    | 8 | ± 2.9 | ± 5.0  |   |                                      |   |   |
|                         |      |     |    | 8 | ± 3.8 | ± 7.9  |   |                                      |   |   |
| Svaldi, Brand et al.    | 2010 | BED | ★  | 1 | 32.8  | 42.4   | ♀ | Trail Making Task B                  | BED>OW time   | 6 |
|                         |      | OW  |    | 1 | 30.7  | 38.3   |   |                                      |   |   |
|                         |      |     |    | 7 | ± 3.5 | ± 12.3 |   |                                      |   |   |
|                         |      |     |    | 8 | ± 3.9 | ± 13.1 |   |                                      |   |   |

|                             |      |                 |    |   |       |        |   |  |                           |   |
|-----------------------------|------|-----------------|----|---|-------|--------|---|--|---------------------------|---|
| Reiter, Heinze et al.       | 2017 | BED             | ★  | 2 | 28.3  | 29.0   | ♂ | Trail Making Task B                        | BED=NW time               | 5 |
|                             |      |                 |    | 2 | ± 6.6 | ± 9.4  |   |  |                           |   |
|                             |      | NW              |    | 2 | 26.1  | 27.8   |   |  |                           |   |
|                             |      |                 |    | 2 | ± 4.4 | ± 4.5  |   |  |                           |   |
| Dingemans, Vanhaelen et al. | 2019 | BED             | ★  | 2 | 38.5  | 32.8   | ♂ | Trail Making Task (computerised)           | BED(DEP+)=BED(DEP-B-A)=NW | 6 |
|                             |      | DEP             |    | 5 | ± 7.4 | ± 8.5  |   |  |                           |   |
|                             |      | -               |    |   |       |        |   |  |                           |   |
|                             |      | BED<br>DEP<br>+ |    | 6 | 37.6  | 34.2   |   |  |                           |   |
|                             |      |                 |    | 6 | ± 6.2 | ± 9.9  |   |  |                           |   |
|                             |      | NW              |    | 5 | 23.5  | 36.7   |   |  |                           |   |
|                             |      |                 |    | 6 | ± 2.8 | ± 12.3 |   |  |                           |   |
| Galioto, Spitznagel et al.  | 2012 | BED             | ♠□ | 4 | 45.4  | 43.6   | ♂ | Trail Making Task (computerised)           | BED=OW                    | 5 |
|                             |      |                 |    | 1 | ± 6.1 | ± 11.5 |   |  |                           |   |
|                             |      | OW              |    | 9 | 44.9  | 41.2   |   |  |                           |   |
|                             |      |                 |    | 0 | ± 6.6 | ± 10.4 |   |  |                           |   |
| Aloi, Rania et al.          | 2020 | BED             | ♣□ | 3 | 38.9  | 44.2   | ♂ | Trail Making Task B, Trail Making Task B-A | BED<NW, BED=OW            | 5 |
|                             |      |                 |    | 5 | ± 6.9 | ± 10.7 |   |  |                           |   |
|                             |      |                 |    |   |       |        |   |  |                           |   |
|                             |      | OW              |    | 3 | 36.4  | 49.6   |   |  |                           |   |
|                             |      |                 |    | 2 | ± 6.8 | ± 9.9  |   |  |                           |   |
|                             |      | NW              |    | 2 | 23.0  | 46.7   |   |  |                           |   |
|                             |      |                 |    | 6 | ± 0.8 | ± 11.1 |   |  |                           |   |
| Duchesne, Mattos et al.     | 2010 | BED             | ♠□ | 3 | 35.9  | 33.3   | ♂ | Wisconsin Card Sorting Task                | BED<OW                    | 5 |
|                             |      |                 |    | 8 | ± 2.9 | ± 5.0  |   |  |                           |   |

|  |      |                 |    |  |                 |   |           |            |   |                                   |   |  |   |
|--|------|-----------------|----|--|-----------------|---|-----------|------------|---|-----------------------------------|---|--|---|
|  |      |                 |    |  | OW              | 3 | 36.6      | 35.4       |   |                                   |   |  |   |
|  |      |                 |    |  |                 | 8 | $\pm 3.8$ | $\pm 7.9$  |   |                                   |   |  |   |
| Aloi,<br>Rania<br>et al.               | 2015 | BED             | ♠□ |  |                 | 4 | 35.2      | 30.6       | ♀ | Wisconsin<br>Card Sorting<br>Task | BED<NW  |  | 6 |
|  |      |                 |    |  |                 | 5 | $\pm 6.5$ | $\pm 10.9$ |   |                                   |   |  |   |
|  |      |                 |    |  | NW              | 4 | 20.2      | 25.6       |   |                                   |   |  |   |
|  |      |                 |    |  |                 | 5 | $\pm 1.6$ | $\pm 3.5$  |   |                                   |   |  |   |
| Kelly,<br>Bulik<br>et al.              | 2013 | BED             | ♦□ |  |                 | 5 | 24.5      | 19.3       | ♀ | Wisconsin<br>Card Sorting<br>Task | BE=NW   |  | 5 |
|  |      |                 |    |  |                 | 0 | $\pm 5.1$ | $\pm 1.7$  |   |                                   |   |  |   |
|  |      |                 |    |  | NW              | 6 | 23.4      | 19.0       |   |                                   |   |  |   |
|  |      |                 |    |  |                 | 6 | $\pm 5.2$ | $\pm 1.3$  |   |                                   |   |  |   |
| Dingema<br>ns,<br>Vanhael<br>en et al. | 2019 | BED<br>DEP<br>- | ★  |  |                 | 2 | 38.5      | 32.8       | ♂ | Wisconsin<br>Card Sorting<br>Task | BED(DEP+)=BED(DEP-)<br>)=NW   |  | 6 |
|  |      |                 |    |  |                 | 5 | $\pm 7.4$ | $\pm 8.5$  |   |                                   |   |  |   |
|  |      |                 |    |  | BED<br>DEP<br>+ | 6 | 37.6      | 34.2       |   |                                   |   |  |   |
|  |      |                 |    |  |                 | 6 | $\pm 6.2$ | $\pm 9.9$  |   |                                   |   |  |   |
|  |      |                 |    |  | NW              | 5 | 23.5      | 36.7       |   |                                   |   |  |   |
|  |      |                 |    |  |                 | 6 | $\pm 2.8$ | $\pm 12.3$ |   |                                   |   |  |   |
| Blume,<br>Schmidt<br>et al.            | 2019 | BED<br>FA-      | ★  |  |                 | 1 | 41.9      | 38.8       | ♂ | Wisconsin<br>Card Sorting<br>Task | BED(FA+)=BED(FA-)<br>)=OW(FA+)=OW(FA-)<br>perseverative errors<br>BED(FA+)=BED(FA-)<br>)<OW(FA+)=OW(FA-)<br>learning to learn |  | 5 |
|  |      |                 |    |  |                 | 9 | $\pm 5.3$ | $\pm 9.4$  |   |                                   |   |  |   |
|  |      |                 |    |  | BED<br>FA+      | 2 | 42.2      | 37.5       |   |                                   |   |  |   |
|  |      |                 |    |  |                 | 3 | $\pm 6.1$ | $\pm 10.1$ |   |                                   |   |  |   |
|  |      |                 |    |  | OW<br>FA-       | 2 | 42.8      | 40.5       |   |                                   |   |  |   |
|  |      |                 |    |  |                 | 3 | $\pm 4.8$ | $\pm 10.9$ |   |                                   |   |  |   |

|     |   |           |            |
|-----|---|-----------|------------|
| OW  | 2 | 44.1      | 43.4       |
| FA+ | 3 | $\pm 6.6$ | $\pm 10.4$ |

| B | Authors                          | Year | Group | N  | Species | Sex | Paradigm              | Main Finding |
|---|----------------------------------|------|-------|----|---------|-----|-----------------------|--------------|
|   | Rossetti, Spena et al.           | 2013 | BE    | 16 | Rats    | ♀   | Aversive conditioning | BE<CON       |
|   |                                  |      | CON   | 14 |         |     |                       |              |
|   | Moshe, Bekker et al.             | 2017 | BE    | 23 | Rats    | ♀   | Aversive conditioning | BE<CON       |
|   |                                  |      | CON   | 16 |         |     |                       |              |
|   | Oswald, Murdaugh et al.          | 2011 | BE    | 10 | Rats    | ♀   | Aversive conditioning | BE<CON       |
|   |                                  |      | CON   | 10 |         |     |                       |              |
|   | Velázquez-Sánchez, Santos et al. | 2015 | BE    | 8  | Rats    | ♂   | Aversive conditioning | BE<CON       |
|   |                                  |      | CON   |    |         |     |                       |              |
|   | Heal, Goddard et al.             | 2016 | BE    | 15 | Rats    | ♀   | Aversive conditioning | BE<CON       |

|                              |      |     |        |   |             |  |  |
|------------------------------|------|-----|--------|---|-------------|--|--|
|                              |      | CON |        | 1 |             |  |  |
|                              |      |     |        | 7 |             |  |  |
| Chawla,<br>Cordner<br>et al. | 2017 | BE  | 8 Rats | ♂ | Barnes maze | BE>CON (perseveration)<br>(reversal<br>learning) |  |
|                              |      | CON |        | 1 |             |  |  |
|                              |      |     |        | 6 |             |  |  |

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BE(D) – Binge eating (disorder), OW – overweight/obese, NW – normal weight, FA – food addiction, DEP – depression, CON – control, ★ – Eating disorder examination interview, ♠□ – structured clinical interview (SCID-IV, MINI, DIPS and/or MIDI), ♣ – clinical interview not otherwise specified, ♦ – Self-report (EDE-Q, EDSS, BES, EAT26), NOS – Newcastle-Ottawa Scale, BMI summary statistics for Kittel, Schmidt et al. (2017) are in percentiles.