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Chapter

Impulsivity and Compulsivity in Anorexia Nervosa: Cognitive Systems Underlying Variation in Appetite Restraint from an RDoC Perspective

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Abstract

Contemporary nomenclature for anorexia nervosa (AN) describes the eating disorder as transdiagnostic, with overlapping facets of impulsivity and compulsivity contributing to variations in binge-purge, restrictive eating and maladaptive cognitions. It is important to understand how these facets interact, given that those diagnosed with AN often fluctuate and relapse–as opposed to maintaining a stable diagnosis—between Diagnostic and Statistical Manual version 5 (DSM-5) categories, over the life course. The National Institute of Health's Research Domain Criteria (NIH RDoC) subscribes to the transdiagnostic view of mental disorders and provides progressive guidelines for neuroscience research. As such, using the RDoC guidelines may help to pinpoint how impulsivity and compulsivity contribute to the cognitive mechanisms underlying variations in appetite restraint in eating disorders and common psychiatric comorbidities such as anxiety and obsessive-compulsive disorder. Exploring impulsivity and compulsivity in AN from the perspective of the RDoC cognitive systems domain is aided by measures of genetic, molecular, cellular, neural, physiological, behavioural and cognitive task paradigms. Thus, from the standpoint of the RDoC measures, this chapter will describe some of the ways in which impulsivity and compulsivity contribute to the cognitive systems associated with appetite restraint in AN, with the aim of further clarifying a model of appetite restraint to improve treatment interventions.

Keywords: RDoC, cognitive systems, anorexia nervosa, appetite restraint, impulsivity, compulsivity

1. Introduction

The Diagnostic and Statistical Manual version 5 (DSM-5), published in 2013 after a decade of edition 4, has progressed nomenclature for the psychiatric eating disorder anorexia nervosa (AN), according to three main criteria, focusing on the behaviours and cognitions underlying weight restriction and body perception [1]. Moreover, while continuing to be categorical in scope, the DSM-5 also recognises the transdiagnostic nature of AN, with the inclusion of body mass index (BMI) severity clauses: mild,

moderate, severe and extreme. The BMI severity inclusion incorporates the overlapping impulsive and compulsive facets of weight dysregulation in eating disorders. For example, compulsive energy restriction relative to body weight requirements is an important diagnostic feature of AN, as is the intense fear of weight gain, and persistence in behaviour that interferes with weight gain. The third criterion includes disturbance in body perception, with undue influence of self-evaluation and persistent denial of the seriousness of reduced body weight. Restrictive and binge-purge are two subtype classifications of AN determined over the course of 3 months. The former holds if an individual has achieved weight loss by compulsive dieting, fasting or excessive exercise; the latter holds if an individual has engaged in impulsive binge-purge behaviour, including the use of diuretics, enemas, laxatives or self-induced vomiting.

The fifth edition of DSM further clarifies eating disorders and their underlying impulsive and compulsive features, incorporating additional categories such as avoidant/restrictive food intake disorder, rumination disorder, pica (compulsive consumption of non-nutritional substances) and binge eating disorder [2]. In terms of AN in particular, the behavioural (e.g. weight dysregulation) and cognitive (e.g. inflexible thinking and misperception) traits are significantly linked to genetic and environmental vulnerabilities, and more recently, to alterations in brain structure and function, particularly within the hypothalamus, hippocampus, insular cortex, parietal cortex and prefrontal cortex [3]. Furthermore, neuroinflammatory processes that contribute to the "leaky gut-brain" hypothesis of eating disorders may interact with these brain regions, via over-expression of cytokines, such as leukotrienes. Recently, theories about the involvement of neuroinflammatory processes in AN may bridge the gap between genetic susceptibility, environmental causes and changes in brain function, especially with regard to altered hypothalamic leptin and serotonin function. Moreover, memory and evaluative processes associated with dysfunction in the hippocampus and prefrontal cortex may contribute to the compulsive overvaluation of thinness, body dissatisfaction and excessive appetite restriction in AN [4], whereas the link to binge eating appears to overlap with striatal dysfunction and impulsivity [5].

The current understanding of eating disorders in general, and of AN in particular, reflects a view that impulsivity and compulsivity are significant diagnostic personality facets underlying the disorder [6]. While some propose that impulsivity and compulsivity are opposite extremes of a single personality dimension, others view impulsivity as a trait vulnerability that drives compulsivity, with repetitive behaviours that emerge as maladaptive, coping strategies to regulate arousal [7]. In addition, while both impulsive and compulsive traits appear to map onto binge eating, persistent drive for thinness and appetite restraint, with some fluctuation between these conditions [3], research suggests that impulsivity and compulsivity are entirely separate constructs that can present, to varying degrees, in unison [6]. Thus, there is still debate in the eating disorders field as to how impulsivity and compulsivity interact and correspond to the DSM criteria. In an attempt to better understand the roles, and to consider potential mechanisms, here we take the *cognitive systems* RDoC domain and its measurement, to examine the presentation of impulsivity and compulsivity and the link to cognitive processes underlying appetite restraint in AN. Prior to the examination of the RDoC domain and its measurement, next follows a brief summary of the definitions of impulsivity and compulsivity.

2. Impulsivity and compulsivity

Traditional views posit that impulsivity and compulsivity are dissociable states, reflecting neural processes within corticolimbic circuitry that underlie

high arousal and maladaptive aversion avoidance, respectively [8, 9]. However, with the advancement of neuroimaging data within transdiagnostic phenotypes, influenced in part by the updated DSM-5 nomenclature in 2013, and the publication of the RDoC, there appears to be common corticolimbic neural functions that when activated in a certain pattern, correspond to high levels of automaticity, impaired cognitive inhibition, lack of self-control and maladaptive self-regulation [10]. It remains to be elucidated, however, why certain variations in impulsivity and compulsivity present as discrete types of psychiatric disorder. In addition, while common psychiatric comorbidities exist between disorders, as highlighted by the RDoC enterprise, the DSM clearly demonstrates discrete boundaries that also exist between various phenotypes. Thus, examining impulsivity and compulsivity from the transdiagnostic measurement of the RDoC cognitive systems domain may clarify how these constructs merge to form a diagnosis of restrictive or binge purge AN.

2.1 Definitions of impulsivity

The International Society for Research on Impulsivity (ISRI: http://www.impulsivity.org) defines impulsivity as: *behaviours or tendencies to act with less forethought than do most individuals of equal ability and knowledge, or a predisposition towards rapid, unplanned reactions to internal or external stimuli without regard to the negative consequences of these reactions*. Research defines impulsivity broadly as part of a normal range of functioning (as opposed to compulsivity that may reflect a maladaptive coping strategy), and yet it is the frequency of impulsivity that determines whether disorder exists [7, 11]. Moreover, neuropsychological research over the last decade has clarified the multi-faceted nature of impulsivity and its neural correlates [11] that are broadly associated with inattention or narrow/inflexible thinking (cognitive impulsivity) and hyperactivity (behavioural or motor impulsivity). Within these broad definitions, nuances of impulsivity occur [11], highlighted by research studies that deserve additional consideration. For example, choice versus rapid response impulsivity have been identified; the former concerns the preference for immediate over delayed rewards (e.g. temporal or delay discounting), the latter concerns the tendency to act without forethought and out of context with immediate demands [12, 13]. Further distinctions of impulsivity within choice versus response impulsivity have been developed [9]. For example, motor impulsivity reflects an inability to inhibit an inappropriate or misplaced response. Disadvantageous decision-making involves cognitions that underlie risk-taking behaviours, and an inability to avoid danger, threat or some form of personal loss. Choice impulsivity determines a person, who cannot delay the experience of reward (e.g. temporal or delay discounting). Finally, reflection impulsivity refers to an inability to deliberate on the potential outcome of one's actions.

2.2 Definitions of compulsivity

Impulsivity appears related to a natural, arousal response, with some adaptive qualities that are widely researched and effectively defined [11], whereas conversely, there is a lack of consensus about compulsivity – both in terms of its definition and function. However, deficits in attention, perception and repetition of motor or cognitive responses appear to be key facets [9]. A recent formal definition based on neuroscientific research states that compulsivity is *a tendency towards repetitive, habitual actions, repeated despite adverse consequences* [14]. Compulsive, perpetual and ritualised behaviours and cognitions may be attempts to neutralise high levels of arousal and negative affect (e.g., fear, anxiety and perceived threat)

and for the individual to gain a rewarding sense of control. However, in recent years, there have been various attempts to better conceptualise the nuances of compulsivity, and to date four discrete definitions have been emerged [9]. First, contingency-related cognitive inflexibility refers to heightened perseverance, especially in anticipation of receipt of a previously experienced reward. Second, task/attentional set-shifting deficits refer to an inability to alter cognitive strategies as the task/attentional demands change. Third, attentional bias/disengagement concerns the phenomenon of disorder salience, where certain stimuli bias processing resources, which may delay the completion of concurrent cognitive tasks (e.g. the "Food Stroop" task for eating disorders [15]). Finally, habit learning describes repetitive automaticity of behaviours and cognitions that correspond to a previously experienced reward.

2.3 Interactions between impulsivity and compulsivity

A diathesis model has held for many years, whereby the constructs of impulsivity and compulsivity are at opposing ends of a spectrum [9]. Such a model suggests that compulsive, maladaptive coping strategies manage excessively impulsive, automatic arousal reactions to internal and external stimuli. In support of the diathesis model, the Pavlovian Instrumental Transfer (PIT) theory [16] describes a switch from deliberative, controlled, ventral striatal (nucleus accumbens-driven) activation to habitual, repetitive, uncontrolled, dorsal striatal (caudate, putamen-driven) activation associated with reward. Furthermore, psychiatric compulsive cognitions and behaviours may be attempts to reduce high levels of impulsivity, arousal, tension and negative affect [8]. In this vein, trait vulnerability for high levels of impulsivity is associated with the advent and maintenance of psychiatric disorder, whereas the role of compulsivity is less clear, but may provide the individual with a semblance of respite from psychological distress, which is rewarding from an opponent process perspective [17]. Support for this notion comes from the repetitive nature of compulsivity – in that, an element of reward must be present for a cognition or behaviour to be repeated. Furthermore, by repeating the process of tension/stress reduction, an allostatic load alteration occurs to maintain stability within neural circuits, which ultimately contributes to psychiatric disorder [18]. Interestingly, the allostatic load hypothesis of AN is related to changes in basal ganglia dopaminergic and hypothalamic pituitary adrenal (HPA) axis systems [19] that are influenced by elevated inflammatory molecules (e.g. leukotrienes).

3. Impulsivity and compulsivity in AN

Impulsivity is typically associated with the loss-of-control over eating, which is characteristic of the binge-purge AN subtype, bulimia nervosa and binge eating disorder [20]. In contrast, the restrictive AN subtype is associated with disproportionate belief systems about self-control (e.g. preferring the goal of future thinness to present eating), whereas binge eating subtypes have steeper delay discounting rates and disinhibition over rapid eating [20]. Additionally, higher levels of impulsivity in those with bingeing subtypes of eating disorder show lower goal-drive persistence [21]. Interestingly, the bingeing subtypes, including binge-purge AN, also tend to present with other impulse control disorders, such as gambling disorder, which have a higher preponderance for impulsivity, suicidality and cognitive distortions [22]. Higher levels of impulsivity in binge-purge AN subtypes also

correspond to increased difficulties in emotion regulation that may worsen with older age [23]. Finally, perhaps most pertinent to the role of impulsivity in bingeing subtypes of eating disorder is the concept of negative urgency, which is the dispositional tendency to engage in rash action during the experience of negative affect. Women with AN, who score higher on negative urgency, with an experience of negative affect, are significantly more likely to engage in binge eating behaviour [24]. Thus, in the same vein that trait vulnerability for impulsivity underlies a switch from deliberative to compulsive drug taking [25], it might be that a similar vulnerability occurs in AN, underlying a switch – or fluctuation – between impulsive binge eating and compulsive appetite restraint.

Compulsivity in AN refers to the relentless pursuit of appetite restraint and weight loss, which appears to be transdiagnostic and related to obsessive-compulsive and addictive disorders [26]. In fact, obsessive-compulsive personality disorder, and addictive processes are common comorbidities in restrictive AN, alongside anxiety and depression [27, 28]. The compulsive relationship between initially rewarding deliberative behaviours and the relentless pursuit of thinness, supported by excessive exercise, starvation and purging, is associated with aberrant corticostriatal dysfunction and rigid, inflexible cognitive ruminations [25]. Moreover, the physiological effects of excessive weight loss may encourage the development of compulsive traits by altering neuroinflammatory processes within the gut-brain axis that interfere with memory consolidation physiology in the hippocampus and prefrontal cortex, and appetite dysregulation in the hypothalamus. A neural shift within corticolimbic brain areas underlying compulsive behaviour may explain why not all people who experiment with illicit substances become addicted, and not all people who experiment with dieting develop an eating disorder. However, the switch to a compulsive pursuit of thinness and appetite restraint in AN appears rewarding similar to the addictive process [28]. The cause of the switch to compulsive behaviour is not yet elucidated. However, it encompasses trait vulnerability for anxiety and impulsivity, and an initial controlled experience of reward (e.g. the pleasure of self-control and social praise alongside dieting), the development of incentive salience to motivate the continuance of the behaviour, and finally the seeking, or habitual behaviour necessary to repeat the learned reward [29]. Additionally, aberrant opponent processes in corticolimbic circuitry underlying reward deficits and stress surfeits drive compulsivity [29], which for those with AN would mean increasingly dangerous, yet still rewarding, weight loss attempts.

3.1 Multi-faceted elements of impulsivity and compulsivity in AN

Impulsivity and compulsivity may both uniquely contribute, in varying degrees, to certain aspects of AN. Compelling evidence suggests that both facets of impulsivity and compulsivity contribute to eating concerns and restraint in AN [6]. In a recent study of adults with AN by Lavender and colleagues [6], extensive self-report measures were used to confirm that impulsivity was linked to eating concerns and the frequency of loss of control eating. Conversely, compulsivity was associated with the lack of perseverance and restraint, as well as eating and weight concerns. Previously, the RDoC criteria reinforce the notion that anxiety drives the compulsive tendency to engage in repetitive self-starvation in those with AN [28]. This is in line with recent suggestions that impulsivity is associated with heightened anxiety, or negative urgency, which appears to drive maladaptive compulsive strategies in those with eating disorders [30]. **Figure 1** provides a schematic diagram of the link between arousal, anxiety, binge eating, restraint, impulsivity and compulsivity in AN.

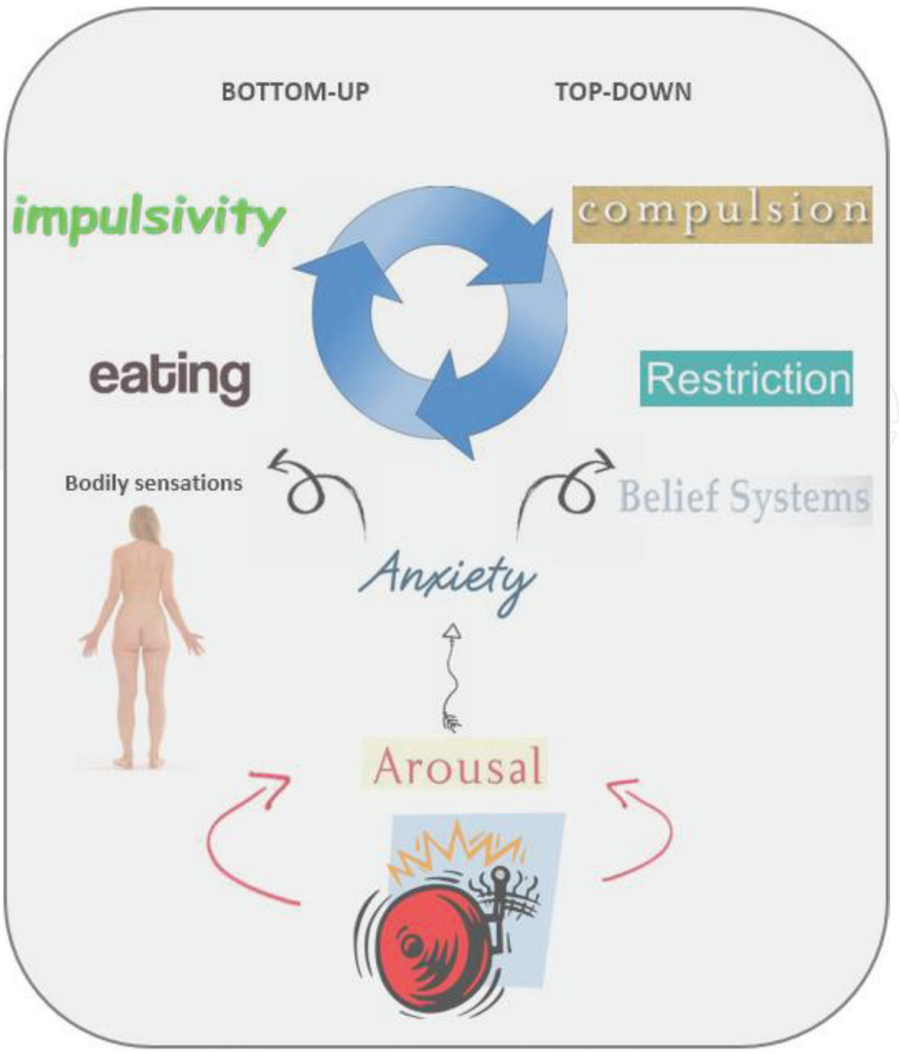


Figure 1.
A schematic diagram describing how impulsivity and compulsivity may interact with bodily sensations (bottom up) and belief systems (top-down) in binge-eating and restricting anorexia nervosa (AN).

4. The RDoC research domains and suggested units of measurement

Some consensus appears in the eating disorder literature as to the role of impulsivity and compulsivity in binge eating and restrictive eating subtypes, respectively. However, there is still debate as to whether these are separate constructs, extremes on a diathesis model, or functioning concomitantly in varying degrees to derive a fluctuating eating disorder phenotype. Moreover, there are other nuances to eating disorders – such as body and self-image distortion, denial of disorder, cognitive deficits including excessive attention to detail, set-shifting abnormalities – that are still not fully elucidated by theories of the neural processes of impulsivity and compulsivity. As such, it is useful to consider the transdiagnostic scope of the RDoC domains and suggested units of measurement, in an attempt to further clarify how impulsivity and compulsivity might contribute to symptoms of the subtypes of AN.

4.1 Five RDoC domains

RDoC comprises of five domains for suggested neuroscientific research areas (see: https://www.nimh.nih.gov/research-priorities/rdoc/constructs/rdoc-matrix.shtml). These are: (i) negative valence systems; (ii) positive valence systems; (iii) cognitive systems; (iv) social processes and (v) arousal and regulatory systems.

Negative valence systems include fear, anxiety, sustained threat, loss and frustrative non-reward. Positive valence systems include reward responsiveness, reward learning and reward valuation. Cognitive systems include attention, perception, declarative memory, language, cognitive control and working memory. Social processes include attachment, social communication, perception and understanding of the self, perception and understanding of others. Finally, arousal and regulatory systems include circadian rhythms and sleep/wakefulness. Against the background of the RDoC domains, given the scope of this article, the cognitive systems domain, linking impulsivity and compulsivity to varying degrees of appetite restraint in AN, will be the focus of the remaining sections.

4.2 Eight RDoC measures

To measure the cognitive systems domain, the RDoC suggests eight neuroscientific genres. These are: (i) genes; (ii) molecules (neurotransmitters); (iii) cells; (iv) neural circuits; (v) physiology; (vi) behaviour; (vii) self-report; and (viii) paradigms. Before considering how cognitive systems and their measurement might aid the understanding of the role of impulsivity and compulsivity in appetite-restraint variations characteristic of AN, the measurement of the cognitive systems domain will be defined below. As a brief introduction, attention may be related to cognitive biases (particularly toward food and body-image stimuli) that maintain cognitive restraint in AN. Perception can be linked to non-conscious sensory mechanisms that may drive maladaptive conscious evaluations of the environment in those with AN. Declarative memories may underlie the AN narrative of the self and the world. Language processing may support the development of the internal narrative associated with AN-related cognitions, particularly in line with becoming and staying thin and in control. Cognitive control refers to the ability of people with AN to excessively regulate their appetite and eating behaviours with cognitive ruminations of goals to stay underweight. Finally, working memory likely underpins the flexible updating of excessively detailed cognitive strategies to achieve the future goal of thinness, and to avoid immediate distractions (e.g. food-related stimuli). Next follows a detailed account of the RDoC definitions of the sub-constructs (attention, perception, declarative memory, language, cognitive control and working memory) and the measurement of the cognitive systems domain.

4.2.1 Attention

According to the RDoC, attention refers to the regulation of capacity-limited systems such as awareness, higher order perception and motor function (e.g. response inhibition). Additionally, the RDoC clarifies that capacity limitation and competition are synonymous with selective and divided attention, respectively, which relate to attentional bias and distraction. The measurement of genes associated with attention has yielded inconclusive findings. However, in terms of neurotransmitters, the RDoC highlights that a balance between GABAergic and glutamatergic systems within the prefrontal cortex is a key to implement attention. Specifically, the control of attention is associated with acetylcholine, dopamine, glutamate, histamine and serotonin. In terms of cells, the RDoC recognises parvalbumin-positive interneurons as linked to the process of attention. Brain circuits associated with the initiation of attention include a balance between the resting state default mode and task positive networks, whereas the subsequent control of attention links to descending and ascending networks with the corticolimbic circuitry. Additionally, the dorsal "where" and ventral "what" visual processing pathways are implicated in attentional neural networks. Physiological measures of attention have yielded most

consistent results according to the RDoC, with functional MRI (fMRI), auditory/visual event-related potentials (ERPs) and peripheral measures such as heart rate and pupillometry. The RDoC goes on to list that behavioural measures associated with attention include task distractibility, attentional lapses versus sustained attention, distractibility, object/feature detection, psychophysics and spatial attention. Finally, in terms of paradigms that measure attention, these include attentional blink, dichotic listening, dual-task paradigms, cueing paradigms, time-series responses and visual search.

4.2.2 Perception

Perception is the process by which computations in the brain extract sensory information to construct a model of the environment, making predictions about the world and guiding action, according to the RDoC. Visual and auditory perception involves various neurotransmitter systems, such as acetylcholine, catecholamines, GABA, glutamate, NMDA, peptides and serotonin. The cells involved in visual perception are magno and parvo cells, parvalbumin-positive interneurons and pyramidal cells, whereas for auditory perception, the cells include cochlear hair cells, cortical and limbic interneurons and ribbon synapses. In terms of neural circuits, subcortical vision involves konio-, magno- and parvo-cells, cortically the supra- and infra-granular layers are involved, and also the dorsal and ventral visual streams. Additionally, the suprachiasmatic nucleus and superior colliculus control saccadic and other visual actions. Additionally, auditory perception includes brain regions such as the anterior insula, brainstem, cochlear, inferior colliculus and the superior temporal gyrus. In terms of physiology, adaption and habituation are measured via fMRI, EEG and ERPs. Behavioural experiments to incorporate visual and auditory perception include discrimination, identification and localisation, learning, priming, reading, stimulus detection and visual acuity. Commonly used paradigms in visual perception research include backward masking (subliminal processing), motion processing, contrast sensitivity, emotion expression identification, face identification, object recognition, reading and visual illusion susceptibility. Commonly used paradigms in auditory perception research include auditory masking, streaming, detection of speech in noise, gating, inhibitory control, the McGurk effect (multisensory), oddball detection, self-monitoring and tone detection. Additionally, olfactory research is an emerging area of interest, with different odours eliciting different perceptual and cognitive systems.

4.2.3 Declarative memory

Declarative memory refers to the acquisition, encoding, storage and retrieval of information gained from the environment. This type of memory, as opposed to non-conscious, non-declarative memory, is important for spatial, temporal and contextual information, which represents a timeframe of events (e.g. episodic), and the organisation of items of memories into facts (semantic). Inferential and flexible extraction occurs from memories in order to update novel sensory information (e.g. Bayesian Inference). According to the RDoC, the neurotransmitters involved in declarative memory include acetylcholine, glutamate, noradrenalin and opioids. In terms on neuronal cell types that support declarative memory, these are glia, granule cells, inhibitory and excitatory interneurons and pyramidal cells. Brain circuitry for memory involves the hippocampus, and connections between the prefrontal and parietal cortices, as well as various other association areas. The physiology that supports declarative memory includes AMPA-related synaptic plasticity, coordinated fronto-temporal oscillatory activity, long-term potentiation and

long-term depression and changes in the fMRI, EEG or other spatial and temporal brain imaging measures. Behaviour associated with declarative memory is measured by discrimination and familiarity tests, or learning, recall and recognition tasks. Finally, various paradigms exist to test declarative memory, including delayed recall, acquired equivalence, list and story learning, paired associative learning and transitive inference.

4.2.4 Language

The RDoC describes cognitive processes underlying language as a system of shared symbolic representations of the external environment, incorporating abstract and self-related notions that aid thought and communication. Currently, there are no conclusive data regarding the genes, neurotransmitters or cells that contribute to language. However, the neural circuitry involves the inferior fronto-temporo-parietal cortices, superior and middle temporal cortices, with considerable involvement of the limbic system, motor and sensory cortices. Behaviour is measured in the form of coherent discourse and sentences, and incorporates Wernicke (temporal cortex) and Broca's (frontal cortex) areas for speech comprehension and production, respectively. Experimental paradigms include discourse analyses and eye-tracking equipment.

4.2.5 Cognitive control

The RDoC defines cognitive control as the processes that modulate the operation of other cognitive and affective systems in the brain. Cognitive control processes enable the achievement of goal-oriented behaviour, when pre-potent responses are not adequate for current demands. Control processes are also important under conditions of uncertainty, or novelty, where appropriate responses are selected from various competing options. Cognitive control involves three sub-processes, according to the RDoC: goal selection (updating, representation and maintenance), response selection (inhibition/suppression), and performance monitoring. Firstly, goal selection involves dorsolateral prefrontal and parietal cortex function, as well as inhibition of the default mode network. The neurotransmitter systems involved include cholinergic, dopaminergic, GABAergic, glutamatergic and norepinephrine. Gamma synchrony and pupillometry are some physiological measures used to detect goal-oriented cognitive control, alongside behavioural measures of distractibility. Experimental paradigms include cued stimulus-response reversal tasks, task switching and tower tasks (e.g. Hanoi, London). In addition, response selection tasks measure impulsive behaviour, using paradigms such as the Flanker, Simon and Stroop tests. Furthermore, response inhibition typically involves the parietal cortex, pre-supplementary motor area and ventro-fronto-striatal circuitry. Physiology of response inhibition is probed using, for example, pupillometry, eye-blink startle paradigms and transcranial magnetic stimulation. Tasks associated with response inhibition include Go/No-Go and Stop-Signal Reaction Time tasks. Finally, performance monitoring appears to involve serotonergic and dopaminergic systems within the anterior cingulate cortex, pre-supplementary motor area and insula and measured by conflict monitoring tasks.

4.2.6 Working memory

The RDoC definition states that working memory is active maintenance and flexible updating of goal or task relevant information (e.g. holding in mind bits of information, strategies and plans) in a limited capacity store that resists

interference. This active maintenance could involve flexible binding together of bits of information, may be internally represented despite external cues and holding in mind may be temporary, although this could be a function of interference. As such, according to the RDoC, working memory constitutes four sub-components: active maintenance, flexible updating, limited capacity and interference control. Active maintenance involves D1 dopamine receptor function, dopamine, GABA, glutamate and NMDA within inhibitory and pyramidal neuron populations. Furthermore, the cells responsible for inhibitory control include calbindin, calretinin, parvalbumin and distinct types of inhibitory neurons. Neural circuitry for active maintenance includes dorsolateral and ventrolateral prefrontal-parietal cortex and cingulate-thalamo-limbic networks. Additionally, medium spiny neurons in the basal ganglia enable flexible updating. Delta, theta and gamma waves are also implicated with the use of EEG recordings. Working memory cognitive paradigms include change detection tasks, complex span tasks, delayed match to sample and non-sample, letter-number sequencing, N-Back, self-ordered pointing, sequence encoding and reproduction and Sternberg item recognition.

4.3 RDoC measures of cognitive systems and the role of impulsivity and compulsivity in AN

See **Table 1** for the summary of the RDoC cognitive systems sub-domains and their link to impulsivity and compulsivity in AN. The RDoC cognitive systems domain includes the constructs attention, perception, declarative memory, language, cognitive control and working memory, and all are pertinent in the processes of appetite control in AN. Before considering the RDoC measures of these constructs in relation to AN phenotypes, the broad links to these constructs are summarised. First, attentional processes are associated with regulatory control and response inhibition, and underlie the conscious and non-conscious processes of attentional bias to food stimuli [15, 31]. For example, attention is influenced by incentive salience as reflected in eye-blink startle responses to disorder-specific cues [32], which could drive the cognitive tendency for delayed reporting of disorder-specific stimuli [15]. Second, perception is related to this, and encompasses Bayesian Inference and epistemic foraging, or in AN-related terms, excessive cognitive sampling (e.g. of internal or external stimuli), to create rigid, inflexible cognitive models about the self, world and others, especially under conditions of uncertainty [4]. Third, declarative memory links to perception, in that episodic memory for recent food consumption for example, alters semantic memory regarding the metabolic and hedonic need for food [33]. However, recent research has not been able to replicate the finding that focused attention during eating improves later appetite control, and so, more research is required to determine under what conditions attention is associated with appetite control [34]. Fourth, language processes may support the internal narrative that contributes to ruminations underlying a distorted view of self and of body image [35]. Cognitive control may explain the compulsive nature of cognitive ruminations in AN, which bias decision-making and contribute to affect dysregulation [36]. Fifth, cognitive control of appetite may involve either goal-oriented cognitive inhibition of distracting stimuli, or pre-potent motor response inhibition [33]. Finally, working memory may contribute to the cognitive control of appetite by keeping in mind, for delayed periods, independent of the initial stimulus (e.g. food), detailed and complex strategies to avoid eating [4]. Next follows a more detailed account of how the RDoC measures of cognitive systems might contribute to an updated understanding of the role of impulsivity and compulsivity in AN.

4.3.1 Impulsivity

Binge-eating AN phenotypes are typically associated with trait impulsivity [5, 8, 9]. As such, the level of distraction (by food or body images for example) caused attention, as well as deficits in response inhibition (e.g. go/no-go, Stop Signal tasks and pre-pulse inhibition tasks), is likely to be a predictor of disorder severity reflected in distinct neural functioning [37]. Specifically, the function of acetylcholine, dopamine, glutamate, histamine and serotonin, and related stress hormones, particularly in the prefrontal-basal ganglia circuitry, are likely to be significantly indicative of the degree of impulsivity, and the likelihood that a binge-eating AN phenotype is present [38]. Similarly, neuronal variability in the ventral attentional resting state network may well reflect a greater propensity for impulsivity, and deficits in appetite control [39]. Heart rate variability and pupillometry may also highlight non-consciously derived arousal subserving impulsive tendencies and the binge-eating subtypes [40, 41].

4.3.2 Compulsivity

Restrictive subtypes of AN are typically associated with compulsivity, for example, inflexible ruminations and excessive attention to detail that appear to regulate anxiety and maintain complex self-concepts about weight loss [35]. Moreover, altered perceptual processes are associated with specific central coherence and empathy deficits, such as an inability to perceive a global view [42], read the mind in the eyes [43] and alexithymia–an inability to recognise one's own or others' internal states [44]. Ineffective affect regulation, particularly in terms of anxiety and depression, may drive the compulsive tendency to rely on cognitive evaluations for environmental navigation and decision-making in those with restrictive AN [4]. Furthermore, studies of subliminal priming demonstrate that restrictive AN patients, particularly those with high levels of anxiety, experience

RDoC cognitive systems sub-domain with definition	**Measures of impulsivity**	**Measures of compulsivity**
Attention: *The regulation of capacity-limited systems such as awareness, higher-order perception and motor function (e.g. response inhibition).*	Binge-purge severity is significantly associated with impulsivity, and is predicted by the level of distraction (by food or body images for example) caused to attention, as well as deficits in response inhibition (e.g. go/no-go, Stop Signal tasks and pre-pulse inhibition tasks). This is reflected in distinct neural functioning within fronto-striatal circuitry [37]. Acetylcholine, dopamine, glutamate, histamine and serotonin function, and related stress hormones, particularly in the prefrontal-basal ganglia circuitry, are related to the degree of impulsivity, and the likelihood that a binge-eating AN phenotype is present [38].	Restrictive subtypes of AN are typically associated with compulsivity, for example, inflexible obsessive-compulsive ruminations and excessive attention to detail that appear to regulate anxiety and maintain complex self-concepts about weight loss [35]. An imbalance between GABAergic and glutamatergic systems within the prefrontal cortex is key to the compulsive function of attention (e.g. towards food and body stimuli) in AN. Task distractibility, attentional lapses versus sustained attention, distractibility, object/feature detection, psychophysics and spatial attention are common cognitive tasks used to measure attentional compulsivity.

RDoC cognitive systems sub-domain with definition	Measures of impulsivity	Measures of compulsivity
Perception: *The process by which computations in the brain extract sensory information to construct a model of the environment, making predictions about the world and guiding action.*	Heart-rate variability and pupillometry may highlight non-consciously derived perceptual processes sub-serving impulsive tendencies and the binge-eating subtypes [40, 41]. The dorsal 'where' and ventral 'what' visual processing pathways are implicated in rapid responses to environmental stimuli. Backward masking (subliminal processing), motion processing, contrast sensitivity, emotion expression identification, face identification, object recognition, reading, and visual illusion susceptibility. See also the McGurk effect (multisensory), oddball detection, self-monitoring and tone detection.	Altered perceptual processes are associated with specific central coherence and empathy deficits, such as an inability to perceive a global view [42], read the mind in the eyes [43] and alexithymia - an inefficiency in perceiving one's own or others' internal states [44]. A switch from deliberative dieting to compulsive appetite restriction may involve a switch from activation of incentive salience networks within nucleus accumbens systems in favour of dorsal striatum networks associated with Pavlovian Instrumental Transfer [25]. The suprachiasmatic nucleus and superior colliculus control saccadic and other visual actions associated with excessive epistemic foraging of the environment, measured by eye-tracking equipment.
Declarative memory: *The acquisition, encoding, storage and retrieval of information gained from the environment.*	Declarative memory is important for spatial, temporal and contextual information, which represents a timeframe of events (e.g. episodic), and the organisation of items of memories into facts (semantic). Inferential and flexible extraction occurs from memories in order to update novel sensory information (e.g. Bayesian Inference). This may underlie conditioned fear and threat-related impulsive responses to food, eating and the environment. Fluctuating levels of acetylcholine, glutamate, noradrenalin and opioids. In terms on neuronal cell types that support declarative memory, these are glia, granule cells, inhibitory and excitatory interneurons and pyramidal cells.	Compulsive cognitive ruminations and biases, which reflect in eye-tracking studies of vigilance and avoidance [46] may therefore become more deeply conditioned and consolidated in connected regions such as hippocampal, prefrontal cortex, and cholinergic and striatal dopaminergic neurons [47]. This may alter non-conscious memory formation and increase the probability of cognitive biases to disorder-relevant stimuli [48].
Language: *A system of shared symbolic representations of the external environment, incorporating abstract and self-related notions that aid thought and communication.*	Inferior fronto-temporo-parietal cortices, superior and middle temporal cortices, with considerable involvement of the limbic system, motor and sensory cortices. This may underlie the negative self-talk and phonological loop activation associated with impulsive responses to perceived threat and subsequent binge eating, which acts as a maladaptive coping strategy to suppress negative affect.	Coherent discourse analysis, which is reflected in neural function of Wernicke (temporal cortex) and Broca's (frontal cortex) areas for speech comprehension and production, respectively could measure restrictive eating behaviour that may be driven by cognitive ruminations. Experimental paradigms include discourse analyses and eye-tracking equipment.

RDoC cognitive systems sub-domain with definition	Measures of impulsivity	Measures of compulsivity
Cognitive control: *The processes that modulate the operation of other cognitive and affective systems in the brain. Cognitive control processes enable the achievement of goal-oriented behaviour, when pre-potent responses are not adequate for current demands.*	Neuronal variability in the ventral attentional resting state network may well reflect a greater propensity for impulsivity, and deficits in appetite control [39]. Varying levels of control of attention is associated with levels of fluctuating acetylcholine, dopamine, glutamate, histamine and serotonin. Parvalbumin-positive interneurons are linked to the process of attentional control.	Ineffective affect regulation, particularly in terms of anxiety and depression, may drive the compulsive tendency to rely on cognitive evaluations for environmental navigation and decision-making in those with restrictive AN [4]. A discrete balance between GABAergic and glutamatergic neurotransmitter function in the prefrontal cortex may underpin excessive cognitive control of appetite in restrictive AN, and superior performance on planning tasks [4].
Working memory: *The active maintenance and flexible updating of goal or task relevant information (e.g. holding in mind bits of information, strategies, and plans) in a limited capacity store that resists interference.*	A balance between the resting state default mode and task positive networks underlies the maintenance of working memory and the subsequent control of attention links to descending and ascending networks with the corticolimbic and parietal cortex circuitry.	Studies of subliminal priming (with food images for e.g.) demonstrate that restrictive AN patients, particularly those with high levels of anxiety, experience the greatest interference to cognitive processes such as working memory [31, 45]. Greater working memory capacity may in turn contribute to the holding in mind of excessively detailed cognitive ruminations (e.g. epistemic foraging) in the absence of food stimuli, which subsequently resists interference (e.g. from interoceptive or exteroceptive stimuli).

Table 1.
RDoC cognitive systems sub-domain definitions and measures of impulsivity and compulsivity in relation to anorexia nervosa (binge-purge and restraint subtypes).

interference to cognitive processes, such as working memory [31, 45]. Greater working memory capacity may in turn contribute to the holding in mind of excessively detailed cognitive ruminations in the absence of food stimuli. As such, a discrete balance between GABAergic and glutamatergic neurotransmitter function in the prefrontal cortex may underpin excessive cognitive control of appetite in restrictive AN, and superior performance on working memory and planning tasks [4]. Moreover, a switch from deliberative dieting to compulsive appetite restriction may involve a switch from activation of incentive salience networks within nucleus accumbens systems in favour of dorsal striatum networks associated with Pavlovian Instrumental Transfer [25]. Compulsive cognitive ruminations and biases, which reflect in eye-tracking studies of vigilance and avoidance [46] may therefore become more deeply engrained and consolidated in connected regions such as hippocampal, cholinergic and striatal dopaminergic neurons [47]. This may alter non-conscious memory formation and increase the probability of cognitive biases to disorder-relevant stimuli [48]. Finally, a propensity to higher levels of anxiety is associated with compulsive ruminations in AN, as well as the common presentation of obsessive-compulsive and other psychiatric disorders [49].

5. Conclusions

Considering the facets of impulsivity and compulsivity in AN from the perspective of the cognitive systems, RDoC domain may aid understanding of the nuances of appetite control in eating disorders. Traditionally, impulsivity is associated with binge-eating subtypes, which incorporates response inhibition deficits, craving, errors of perception, deficits in affect regulation and decision-making. In contrast, compulsivity appears to underlie the drive for thinness and excessive cognitive ruminations about food, eating, shape and weight concerns, and the control of eating in restrictive AN. As such, attention, declarative memory systems, perceptual processes, language and internal narratives, cognitive control processes and working memory–to hold consciously in mind complex strategies and detailed plans–appear significantly associated with restrictive AN. Moreover, heightened anxiety and altered incentive salience, non-consciously represented by mesolimbic function, appear to drive the compulsive maladaptive coping strategies. Thus, impulsivity and compulsivity may not form a diathesis model in AN, but they may rather overlap. Given this potential overlap, it might be that treatment interventions effectively treat one and not the other, which could form a basis for relapse. For example, altering maladaptive, compulsive cognitions during cognitive-behavioural therapy treatment without sufficiently altering impulsive, non-consciously-derived appetitive arousal and anxiety (to food or body images, for example), could drive the eventual re-emergence of maladaptive cognitions and relapse.

The popularity and relative efficacy of cognitive behavioural therapy for eating disorders may be due, in part, to the effective measurement of conscious, compulsive restraint cognitions – with self-report or neurocognitive paradigms for example – that may be easier to measure than non-consciously derived impulsive tendencies. Despite this, standard treatments for eating disorders continue to be subject to high relapse rates. However, the RD0C provides suggestions for other measures, such as cellular systems, genes, molecules (neurotransmitters) and neural systems that may well influence conscious compulsions, but are themselves functioning non-consciously within biological systems. With this in mind, measures of impulsivity (e.g. anxiety, appetitive and non-conscious responses to food) may help to inform treatment efficacy, alongside more deliberative, psychological measures of compulsivity (e.g. self-report, neurocognitive tasks). Measuring the overlap between impulsivity and compulsivity in AN, from the perspective of the RDoC cognitive systems domain, may enable a more accurate model of appetite restraint that can improve relapse rates post-treatment.

Conflict of interest

The author declares no conflict of interest.

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