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Subliminal food images compromise superior working memory performance in women with restricting anorexia nervosa

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ABSTRACT

Prefrontal cortex (PFC) is dysregulated in women with restricting anorexia nervosa (RAN). It is not known whether appetitive non-conscious stimuli bias cognitive responses in those with RAN. Thirteen women with RAN and 20 healthy controls (HC) completed a dorsolateral PFC (DLPFC) working memory task and an anterior cingulate cortex (ACC) conflict task, while masked subliminal food, aversive and neutral images were presented. During the DLPFC task, accuracy was higher in the RAN compared to the HC group, but superior performance was compromised when subliminal food stimuli were presented: errors positively correlated with self-reported trait anxiety in the RAN group. These effects were not observed in the ACC task. Appetitive activation is intact and anxiogenic in women with RAN, and non-consciously interacts with working memory processes associated with the DLPFC. This interaction mechanism may underlie cognitive inhibition of appetitive processes that are anxiety inducing, in people with AN.

1. Introduction

Individuals with anorexia nervosa (AN) are severely emaciated (less than 85% normal body weight), are excessively fearful of weight gain and avoid food intake (American Psychiatric Association, 2002; World_Health_Organisation, 2007). The DSM-IV diagnoses two subtypes: restricting AN (RAN) is defined by deliberate food restriction whereas binge-purging AN (BPAN) also has sporadic episodes of food consumption (followed by purging behavior). Dysfunctional eating behavior is strongly associated with cognitive traits that may underpin the control of appetite. For example, people with AN are ascetic and extremely self-disciplined (Fassino et al., 2006), strive for perfection and are obsessional (Davies, Liao, Campbell, & Tchanturia, 2009), attend excessively to detail (Lopez, Tchanturia, Stahl, & Treasure, 2009), may have a genetic predisposition to be cognitively inflexible (Holliday, Tchanturia, Landau, Collier, & Treasure, 2005), are preoccupied with food and have anxiogenic concerns about shape, weight and eating (Fairburn & Harrison, 2003). Furthermore, obsessive–compulsive disorder (OCD) is commonly comorbid in people with AN, especially RAN (Steinglass & Walsh, 2006).

It is unclear, however, how these traits are linked to brain processes, although these cognitive traits are likely to be associated with PFC functions underlying attention, planning, self-reference and working memory. Subcortical activation interacts with executive functions (e.g. cognitive inhibition, working memory, and conflict monitoring) to regulate attention and

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modulate the saliency of a stimulus (Gazzaley et al., 2007). Dysregulation between the PFC, visual cortex and appetitive activation associated with the striatum may underlie dysfunctional cognitive traits in those with eating disorders and could modulate the reward value of a food stimulus. Additionally, excessive PFC function in people with RAN may compensate for reduced or aberrant activation in mesolimbic appetite regions or conversely, the cognitive inhibition of an otherwise intact but anxiogenic subcortical response (Kaye, Fudge, & Paulus, 2009).

Whilst the anterior cingulate cortex (ACC), a monitor for conflict and prediction error, may be associated with eating disorders particularly in response to body dissatisfaction (Friederich et al., 2010), it is potentially the DLPFC that is most strongly implicated in aberrant appetitive responses in those with RAN. For example, functional magnetic resonance imaging (fMRI) studies of women with eating disorders shows aberrant activation in the DLPFC (Brooks et al., 2011, 2012b; Brooks, Savov, Allzén, Fredriksson, & Schiöth, 2012a; Uher et al., 2003). Furthermore, activation of the DLPFC is associated with successful appetite suppression (Hollmann et al., 2011). Artificial stimulation of the DLPFC using repetitive Transcranial Magnetic Stimulation (rTMS) reduces food-induced craving (Van den Eynde et al., 2010), and improves working memory performance (Andrews, Hoy, Enticott, Daskalakis, & Fitzgerald, 2011; Zanto, Rubens, Thangavel, & Gazzaley, 2011) Thus, increased DLPFC activation in females with AN could reflect cognitive inhibition of appetitive responses, for example, associated with working memory ruminations about how to control one's eating.

Subliminal stimuli activate subcortical responses that are independent of PFC processes, and such stimuli can influence cognitive processes (Banse, Seise, & Zerbes, 2001; Fazio & Olson, 2003; Gray, 2001; Hartikainen, Ogawa, & Knight, 2000; Murphy & Zajonc, 1993). (LeDoux, 1996) suggests that a 'quick and dirty' neural pathway relays sensory information from the retina directly to the visual cortex and subcortical regions without engaging conscious processes associated with the PFC. Baars, in his Global Workspace Theory (GWT) suggests that unconscious processes, particularly derived from visual stimuli, interact with cognitive processes like working memory (Baars & Franklin, 2003) to set the context for a consciously-perceived self-relevant goal. This theory seems to fit well with the behavior of a person with RAN, where eating patterns and life events in general are rigidly controlled by self-imposed strategies that ultimately maintain a suppressing effect on appetitive processes, whereby the origin is largely unconsciously derived.

Against this background, subliminally presented anxiety-provoking stimuli (e.g. ego-threats and body image cues) affect action choices in people with eating disorders (Meyer & Waller, 1999; Waller & Barnes, 2002) although evidence for an unconsciously-derived cognitive bias towards food in AN patients is inconclusive. In one study using a Startle Eyeblink Modulation (SEM) task, bias towards appetitive stimuli is independent of conscious cognitive control (Friederich et al., 2006). However, apart from a study examining distractibility in AN, which found no interference effect (e.g. increased errors and/or response times) when subliminal stimuli were presented (Dickson et al., 2008), there are no other studies directly measuring unconsciously-derived cognitive bias to food stimuli in people with AN. One recent study used the subliminal presentation of fearful faces to show that automatic anxiety responses increase the negative evaluation of food images in women with AN (Soussignan, Jiang, Rigaud, Royet, & Schaal, 2010).

This study has used two cognitive tasks (*N*-back and Go/No-Go tasks) associated with the PFC with subliminal food, aversive and neutral images embedded in the tasks. The rationale was to examine whether interference is a general function, or specific to the ACC or DLPFC. The *N*-back task measures working memory (Kane, Conway, Miura, & Colflesh, 2007), and the delay-sensitive neuronal circuitry of the DLPFC is believed to subserve working memory performance (Petrides, 2005). Additionally, the *N*-back task includes different levels of difficulty, such that greater engagement of DLPFC processing can be achieved. A greater level of cognitive engagement may prevent bottom-up appetitive activation from being fully processed, or, conversely, provide a greater platform for non-consciously perceived mesolimbic appetitive responses to interfere with cognitions. The Go/No-Go task measures cognitive inhibition of pre-potent responses, and activates the behavioral inhibition and activation systems in the brain (Amodio, Master, Yee, & Taylor, 2008). The inferior frontal cortices, including the ACC are associated with inhibition of pre-potent responses, especially in response to normally pleasant stimuli (Albert, Lopez-Martin, & Carretie, 2010). Additionally, subliminal primes are robustly shown to activate responses in the striatum, followed by a PFC-related inhibition of this response tendency. Thus, it is plausible that one or both of these PFC regions may interact with subliminal stimulation in those with RAN, although it is predicted that DLPFC function, which is most associated with cognitive inhibition of appetite, represented by the *N*-back task, will be most disturbed in those with RAN.

The following hypotheses have been tested:

(1) Subliminal salient (food and aversive) images in comparison to subliminal neutral images will interfere with performance during both PFC cognitive tasks (by reducing accuracy and increasing response times to targets) in all participants.
(2) Subliminal food stimuli will cause more interference in women with RAN (than in HC women) relative to aversive and neutral stimuli, and the interference will correlate with measures of anxiety.
(3) Differential interference effects will be observed between the cognitive tasks in women with RAN: there will be more interference on the DLPFC task (i.e. *N*-back) during the presentation of subliminal food stimuli relative to the ACC task (i.e. Go/NoGo). Furthermore, greater engagement of the PFC (e.g. during the 2-back version of *N*-back) will show differential interference effects when interacting with subliminal stimuli (e.g. more or less errors during the presentation of food stimuli in the RAN group).