



## Review

# Neurobehavioural correlates of body mass index and eating behaviours in adults: A systematic review

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## ARTICLE INFO

## Article history:

Received 13 July 2012

Received in revised form

24 September 2012

Accepted 12 November 2012

## Keywords:

Obesity

Impulsivity

BMI

Neuropsychology

Executive functions

Food motivation

Five-Factor Model

Big Five

Personality

Self-control

Sensitivity to reward

Reliability

## ABSTRACT

The worldwide increase in obesity has spurred numerous efforts to understand the regulation of eating behaviours and underlying brain mechanisms. These mechanisms can affordably be studied via neurobehavioural measures. Here, we systematically review these efforts, evaluating neurocognitive tests and personality questionnaires based on: (a) consistent relationship with obesity and eating behaviour, and (b) reliability. We also considered the measures' potential to shed light on the brain mechanisms underlying these individual differences. Sixty-six neurocognitive tasks were examined. Less than 11%, mainly measures of executive functions and food motivation, yielded both replicated and reliable effects. Several different personality questionnaires were consistently related to BMI. However, further analysis found that many of these questionnaires relate closely to Conscientiousness, Extraversion and Neuroticism within the Five-Factor Model of personality. Both neurocognitive tests and personality questionnaires suggest that the critical neural systems related to individual differences in obesity are lateral prefrontal structures underpinning self-control and striatal regions implicated in food motivation. This review can guide selection of the highest yield neurobehavioural measures for future studies.

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## Contents

1. Introduction .....	280
1.1. A brain-based approach to obesity research .....	280
1.2. Advantages of neurobehavioural measures .....	280
1.3. Eating behaviours related to neurobehavioural measures .....	281
1.4. Fragmentation of neurobehavioural evidence .....	281
1.4.1. Neurocognitive tasks .....	281
1.4.2. Personality questionnaires .....	281
1.5. Reliability .....	281
1.6. Diverse measures tap common brain mechanisms .....	282
2. Neurocognitive tasks .....	282
2.1. Search strategy .....	282
2.2. Search results .....	282
2.2.1. Generic stimuli .....	282
2.2.2. Tasks using food stimuli .....	288
2.2.3. Interactions between executive and food motivation tasks .....	288
2.3. Reliability .....	289

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2.4.	Neurocognitive tasks: summary.....	290
3.	Personality questionnaires.....	290
3.1.	General measures of personality—Five-Factor Model.....	290
3.2.	Specific personality questionnaires.....	291
3.3.	Specific eating-related questionnaires.....	291
3.4.	Convergence across constructs.....	291
3.5.	Reliability.....	292
3.6.	Personality scales: summary.....	293
4.	Brain mechanisms.....	293
4.1.	Executive control.....	293
4.2.	Emotion/memory system.....	293
4.3.	Brain mechanisms: summary.....	294
5.	General discussion.....	294
	Conflict of interest.....	295
	Acknowledgements.....	295
	Appendix A. Supplementary data.....	295
	References.....	295

## 1. Introduction

### 1.1. A brain-based approach to obesity research

Health worsens as body-mass index (BMI, weight in kg/height in m<sup>2</sup>) increases (James, 2008), and throughout the world BMI continues to rise (Finucane et al., 2011). This alarming increase is likely due to many interacting factors, ranging from neurobiological mechanisms regulating our behaviour (Speliotes et al., 2010) to public policy, agricultural innovation, and business practices that have significantly lowered the cost and increased the availability of calorie dense food (Chandon and Wansink, 2010; Drewnowski, 2009; Lakdawalla and Philipson, 2002).

While the interaction between individual tendencies and a rapidly changing food environment seems to be critical in the increasing prevalence of obesity (Levitsky, 2005), not every individual is equally susceptible to these environmental pressures. How do individual differences in the ability to regulate food choices protect against weight gain in the modern environment of cheaper food and increased food consumption? While a variety of biological individual differences can conceivably be at play, those that relate to behaviour are likely to be of high interest and high impact: indeed, many of the current interventions to address the obesity epidemic are aimed at changing individual behaviour, notably through education and public health messages that exhort healthy choices and self-control.

We propose that a better understanding of the regulation of food choice and eating behaviour is crucial to explaining existing variability in BMI and increases in BMI, and may also be helpful in developing rational, tailored interventions to prevent or reverse weight gain, or at least in predicting who might benefit from a given intervention, whether that intervention relies on pharmacological, educational or social mechanisms. We argue that a brain-based view of these behaviours will allow mechanistic links between the growing body of knowledge about genetic and other biological determinants of BMI and the individual behaviours that lead to weight gain. There are several methods available to study the brain mechanisms underlying eating behaviours in humans. The tools of cognitive neuroscience are now being brought to bear on this question, with provocative results emerging from functional neuroimaging (Batterink et al., 2010; Killgore and Yurgelun-Todd, 2005; Martin et al., 2010; Stice et al., 2008, 2010, 2011a; Wang et al., 2001), electrophysiology (Nijs et al., 2010b; Silva et al., 2002), non-invasive brain stimulation (Camus et al., 2009; Fregni et al., 2008; Uher et al., 2005) hormonal manipulations (Batterham et al., 2007; Farooqi et al., 2007; Malik et al., 2008), and genetics (Stice et al., 2011b). While these approaches are useful for understanding

the neural basis of food choice and other eating related behaviours in tightly focused experiments, they are unwieldy for use on the scale of the population level studies that are increasingly seen as necessary to fully understand the multivariate, multi-level determinants of the complex problem of obesity (Dubé et al., 2008).

### 1.2. Advantages of neurobehavioural measures

Neurobehavioural measures offer a potentially valuable intermediate tool: Such measures quantify a particular behaviour (i.e. psychological construct) in a way that can be linked to the brain, and are feasible for large-scale studies. There are two main types of neurobehavioural measures: neurocognitive measures, which are tasks, many with their origins in neuropsychology, that aim to measure specific cognitive-behavioural abilities, and personality questionnaires or scales that capture participants' typical behaviour through (mainly self-reported) responses to behaviour-related questions. Commonly applied behavioural constructs in research on eating include self-control, impulsivity, executive control and sensitivity to reward, among others. Cognitive neuroscience research has begun to identify the neurobiological substrates of these constructs in general, and, more helpfully for our purposes, of specific measures of these constructs. As an example, self-control can be indexed by both a neurocognitive stop-signal task and a questionnaire measure of Conscientiousness. Both of these measures have been linked to maladaptive eating behaviours (Bogg and Roberts, 2004; Nederkoorn et al., 2010), and have been related to prefrontal structures (Aron and Poldrack, 2006; DeYoung et al., 2010). Thus, one or both of these measures, suitable for use in large-scale studies, might shed light on the role of prefrontal cortex in eating behaviours.

This paper aims to systematically review current knowledge regarding neurobehavioural measures in relation to obesity and eating behaviours. We set out to answer a practical question: Is there sufficient evidence to allow the confident selection of neurobehavioural measures, whether personality questionnaires or neurocognitive tasks, to characterize individual differences in BMI or ecologically-relevant eating behaviours in humans? Appropriate neurobehavioural measures must be both ecologically and conceptually valid: that is, (1) there must be a valid link between the measure and BMI or eating behaviours, and (2) the measure must be reliable i.e., reproducible and accurate. The existing literature will be reviewed in regards to these points, as well as considering whether the measures can be related to specific brain systems.

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