The Role of Impulsivity in Obesity as Measured by Inhibitory Control: A Systematic Review

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Abstract

Objective: There is evidence that executive function (and specifically inhibitory control) is related to obesity and eating behaviour. The go-no go task, the Stop Signal Paradigm and the Stroop Task are examples of behavioural tasks to measure inhibitory control.

Methods: This paper systematically reviews the literature on inhibitory control and its role in obesity and eating behaviours. Studies involving animals, particular clinical population (addiction, eating or psychiatric disorder) and work not related to obesity or psychology were excluded. Only papers that examined the relationship between inhibitory control and one or more eating-related measurements (BMI, BMI change or laboratory food intake measures) were included. Twenty one studies met the selection criteria. Computerized tasks to measure inhibitory control were used in the studies analysed in this review.

Results: The studies that used the go-no go task reveal that age can moderate the relationship between impulsivity and body weight or reported no association. Studies using the Stop Signal Paradigm reveal that the results on the task are a predictor of weight loss in both adolescents and adults populations. Studies using the Stroop Task demonstrate a difference between obese and normal weight groups.

Conclusions: These results reveal the role of inhibitory control in obesity. However, a better understanding of the mechanisms behind this connection is needed. We also conclude that performance tasks that measure inhibitory control are able to differentiate between obese and non-obese groups, but it is recommended wider population range and larger samples in future studies.

Keywords: obesity; systematic review; behavioural tasks; impulsivity; inhibitory control.

1. Background

Executive function is a broad term to describe actions and brain functions that underlie flexible goal directed behaviour. The importance of executive function in eating behaviour has been studied in obesity and with relation to body mass index (BMI). Miyake and colleagues (2000) describe executive function as a combination of response inhibition, attention shifting and working memory. It involves organising, monitoring, and altering the settings of lower level cognitive processes such as stimulus detection and motor programming (e.g., Logan & Gordon, 2001; Miller & Cohen, 2001). The current review shall focus on behavioural measure of inhibitory control and its role in obesity and eating behaviours. The advantages of neurobehavioural measures recognized by the literature are the possibility to link the performance to neuronal pathways in the brain, the feasibility to use in large scale studies, and the opportunity to quantify a particular behaviour and provide objective measurements and thus be less prone to observer bias (Dalley, Everitt, & Robbins, 2011; Robbins et al., 2012).

Response inhibition will be described as inhibitory control for the remainder of the review. This process of inhibitory control has been described by the 'executive control model' (Logan, 1985). According to this model, inhibition is a top down process in which a high order system interacts and controls a lower order system. The lower order or subordinate system depends on the higher order executive system for its instructions and resources. Therefore, subordinate choice to act out one intention can be stopped in some cases and replaced by a new intention (Band & van Boxtel, 1999). Logan (1985) describes how the executive system can inhibit the subordinate system and proposed the Stop Signal Paradigm to study this inhibitory paradigm. Barkley (1999) when studying ADHD described three interrelated processes of behavioural inhibition: the ability to withhold a prepotent response, the ability to stop an ongoing response, and interference control. Interference control, on the other hand, is the ability to protect a delay in the decision to respond an ongoing activity from interfering events and responses (Grodzinsky & Barkley, 1999). These processes also describe the taxonomy of the inhibitory construct described by Nigg (2000). Behavioural tasks have been described for each of these categories of inhibitory control. The go-no go task, continuous performance tests, Stop Signal Paradigm and the Stroop Task are examples of such computerised tasks. Deficits in inhibitory control have been classically studied in drug addiction (Moeller et al., 2002). The abnormal neural pathways, specifically dysfunction of the prefrontal cortex, have also been found in obesity (Goldstein & Volkow, 2011). The use of neurocognitive tasks in research with obese people has found increased impulsivity in this group: obese people entering weight reduction programmes have greater deficits in impulse control than lean people using self-report questionnaires (Guerrieri et al., 2009); there have been found to be a link between obesity and impulsivity in the comorbidity between obesity and ADHD in children (Winstanley, Eagle, & Robbins, 2006); the use of alcohol, which causes a decreased capability to inhibit responses, increases food intake (Caton, Ball, Ahern, & Hetherington, 2004).

Reviews to date have focused on temporal discounting on the sensitivity to reward and health behaviours and neurobehavioural measures and obesity. However, the complete literature based on inhibitory control and obesity is yet to be reviewed, which is the focus of the present review.

2. Methods

The relevant literature was identified by a search of the MEDLINE database on 26.12.2013. The search terms included the following keywords: impulsivity OR inhibitory control OR Stop Signal Task (SST) OR go-no go task OR Stroop Task AND obesity OR weight OR BMI. The search included articles from 1985 to the present day.

The search was conducted by one reviewer (M. K.) who assessed the abstracts for inclusion criteria. Studies involving animals and work not related to obesity and psychology were excluded, resulting in a total of 397 papers. Only papers that examined the relationship between the neurocognitive measures of interest (inhibitory control) and one or more eating-related measurements (BMI, BMI change or laboratory food intake measures) were included. We excluded results from a particular clinical population such as smokers, addiction, those with a psychiatric disorder and ADHD as these are populations known to have abnormal inhibitory control and would bias the findings. Studies with eating disorders were also excluded.

Only papers in English providing statistical data confirming the presence or absence of an effect were included.

3. Results

3.1. Literature search results

Our search identified 21 studies which used three computerised measures of inhibitory control. A comprehensive summary of behavioural tasks and their measurable outcomes, can be found in appendix (Appendix). From those 21 studies, seven of the studies used the go-no go task, nine studies used the SST and four studies used the Stroop Task. The Test-retest reliability and internal consistency of these measures related to obesity and eating behaviour can be found in Table 1. Seventeen studies measured inhibitory control on adult female population. The three remaining studies were on groups of mixed sex adolescents aged 11 to 15 years old. Seven of the studies were on obese participants and studied the relationship between BMI and inhibitory control. The remainder of the studies looked at the role of impulsivity in food intake (Guerrieri, Nederkoorn, & Jansen, 2007; Hall, 2012), dietary restraint (Jansen et al., 2009), weight gain (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010) and its potential role in the intention-behaviour gap with regard to individual food consumption (Allan, Johnston, & Campbell, 2010; Allan, Johnston, & Campbell, 2011).

Table 1 summarizes the results, indicating the target population, its age and BMI, as well as the measures used.

Table 1

A List of Studies Using Behavioural Measures to Investigate Obesity and Eating Behaviours

Authors	Sample	Group/ Obese population	Task/ Measure	Visual/ Auditory	Food related task stimulus	Experimental/ Observatory	Food Eating ED	Relation impulsivity - BMI	Mean Age	Mean BMI	BMI	Comments
Pauli-Pott et al. (2010)	177	Obese children	Go-no go/Stop Signal (Reaction times, invalid reactions)	Visual	No	Observational	No		11.3	29.3 (SD 4.3)	X	1. Error rates to predict obese vs. non-obese in younger age group (<11 years old). 2. In younger children age moderated BMI (using go-no go task). However, not found in adolescents. Inattention cores differentiated between age groups - children being more attentive than adolescents as measured by reaction times.
Jansen et al. (2009)	64	Adults-female	Stop Signal Task/dietary restraint	Auditory	No	Experimental	Yes		22.4 (SD 2.6)	19.1 (SD 1.3)		High restraint eaters only over eat when highly impulsive too. Seen under all experimental conditions: control, preload sight of food.
Loeber et al (2012)	20	Adults - mixed	go-no go task 1.Reaction times in go trials 2. responses to distractors (commission errors) 3.comission errors (failing to respond to target words)	Visual	No	Observational	No	No	47.9 (SD 12.5)	38.8 (SD 6.3)	X	Both obese and normal were faster at responding to go-trials.
Guerrierie et al. (2007)	68	Adults-female	Stop Signal Task (SSRT)	Auditory	No	Experimental	Yes (Bogus)		20.3 (SD 3.4)	21.8 (SD 3.0)		Median-split using SSRT was unable to find influence of impulsivity on flood intake (SSRT 159.44 ms).

Nerderkoorn et al. (2010)	74	Adults-female Obese	Stop Signal Task (SSRT) IAT	Auditory	Yes. IAT	No	No	No	19.7 (SD 1.9)	21.5 (SD 2.3)		1. For participants with a high Implicit Preference for snack food, poor inhibitory control significantly influenced weight change. 2. Less effective response inhibition gained more weight than participants with more effective response inhibition.
Nederkoorn et al (2006)	32	Adolescents Obese	Stop Signal Task (SSRT)	Auditory	No	No	No	Yes (Corr.)	13.7	26.6 (SD 4.2)	X	Obese found to be more impulsive on SSRT (186.9 (SD43.5) vs. 166.4 (SD 35.7). 2. SSRT correlated with those who lost most weight during intervention. 3. SSRT did not differentiate between binge eaters and non-binge eaters.
Jasinska et al. (2012)	204	Adults-Mixed	Go-no go (Error Rates)	Visual	Food images	Observational	No	No	19.0 (SD 0.9)	23.5 (SD 4.0)	X	1. Inhibitory control (rate of false alarms) significantly associated with emotional eating scores (DEBQ score). 2. Rate of false alarms had a negative association with tasty healthy choices of the food choice task.
Nederkoorn et al. (2006)	31	Adults-Women Obese	Stop Signal Task (SSRT)	Auditory	No	Observatory	No	Yes	39 (SD 5.3)	40.9 (SD 6.6.)	X	Obese showed prolonged SSRT (in last of 4 blocks) - overall no significance.
Nederkoorn et al, (2009)	57	Adults-female	Stop Signal Task (SSRT)	Auditory	No	Experimental	Yes (Bogus)	No	20.0 (SD 1.4)	22.0 (SD 1.6)		1. Caloric intake correlates significantly with inhibitory control. 2. Hierarchal linear regression showed those who were hungry and impulsive ate the most.
Verbeken et al. (2009)	41	Children Obese	Stop Signal Task (SSRT)	Visual	No	Observatory	No	Yes	12.0 (SD 1.5)	32.3	X	Obese group had less efficient inhibitory control (227 (SD 47.7) vs. 261.9 (SD 63.0)

Guerrieri et al. (2009)	66	Adults-Female	Stop Signal Task (SSRT)	Auditory	No	Experimental	Yes (Bogus)	No	20.8 (SD 2.6)	22.3 (2.6)		1. Caloric intake was greatest for non-dieters with induction of impulsivity. 2. Current dieters increased caloric diet in response to inhibition.
Hall et al. (2008)	64	Adults	Go-no go task	Visual	No	Prospective, non-experimental	No	Yes	19	22.1	X	Behaviour intention for physical activity and consumption for fruit and vegetable was significant for those with strong executive function.
Allan et al. 2010	114	Adults	Go-no go task (Error Rates)/ Stroop (Average median reaction times)	Visual	No	Experimental	2 studies looking at dietary monitori ng tasks.	No	Study 1 (22) Study 2 (22)			Performance on Stroop Task only was a predictor of number of snacks consumed and hence the intention-behaviour gap.
Ratcliff et al. (2010)	264	Adults	Go-no go task (Error Rates)	Visual	No	Observatory	No	No	18.3 (SD 0.6)	43/264 obese	X	Go-no go task did not predict % Body Fat.
Wong et al. (2009)	96	Adults	Go-no go task (Performance Index [(No Go Accuracy/RT)x 100])	Visual	No	Observatory	NO	No	19.5 (SD 2.2)	Not recorded		Go-no go task did not predict intention and prospective behaviour of breakfast consumption.
Hoffmann et al. (2009)	118	Adults-Female	Go-no go task (SSRT)	Auditory	Yes (Images)	Experimental	Yes (Bogus)	No	23	22.2		Automatic affective reactions have a stronger impact on eating behaviour for individuals' lower inhibitory control.
Houben et al. (2011)	29	Adults-Mixed	Stop Signal Task (SSRT)	Visual	No	Experimental	Yes (Bogus)	NO	21.2 (SD 1.8)	23.1 (SD 4.3)		1. Food intake higher in those with low inhibitory control. 2. Inhibition manipulation decreased consump-tion of food paired with stop signal (stop food). In participants with

												high inhibitory control, impulsivity manipulation increased consumption of go food relative to control food.
Allan et al. (2010)	62	Adults	Stroop Test (Incongruent-Neutral RT)	Visual	No	Experiment	Yes (Bogus)	Yes	20.4 (SD 7.1)	22.6		1. Poor Stroop performance associated with greater chocolate consumption. 2. Stroop associated with higher BMI in normal weight participants.
Gunstad et al. (2007)	408	Adults	Stroop Test (Verbal Interference)	Visual	No	Observatory	No	Yes (Verbal interference negatively correlated with BMI)	Younger: 32.4 (SD 9.1) Older: 60.4 (SD 7.6)	Younger: 28.4 (SD 4.4) Older: 29.2 (SD 3.5)		Normal weight individuals outperformed overweight/obese participants on Stroop Task (verbal interference)
Phelan et al. (2011)	29	Adults (Obese and Weight loss maintainers)	Stroop Test (Average median reaction time-Correct trials)	Visual	Yes (words)	Observatory	No	No	WLM: 48.5 (SD 11.4) Obese: 48.3 (SD 7.6)	WLM: 23.7 (SD 1.6) Obese: 34.3 (SD6.7)	X	1. Weight loss maintainers showed slower reaction times for high calorie food than obese and normal weight persons. 2. Obese were fastest to react to high calories food.

3.2. Reliability

Unlike self-report questionnaires of impulsivity, the validity and reliability for behavioural tasks were difficult to determine from the studies identified. Most of the tests used report the construct and predictive validity of a given measurement (Table 2). A test is said to have construct validity if it demonstrates an association between inhibitory control scores and the impulsivity theoretical trait. Whilst predictive validity occurs when the criterion measures are obtained at a time after the test, for example, impulsivity measure and how likely someone is to lose weight. However, validity of a test is redundant without high reliability. The reliability of a measure determines the maximum possible correlation between the measure and a given outcome. Table 2 summarises the reliability scores of the three commonly used measures of inhibitory control. The test-retest reliability measures the stability of a measurement from one occasion to another. A good test-retest reliability was taken to be >0.70 making it more likely that the same concept is measured on both occasions and less likely to be prone to errors. Other reasons for poor test-retest reliability include a learning effect on the task with repetitions or a change in the individual's motivational state. Internal consistency determines how well different components of a test measure the same construct. Therefore, a poor internal consistency taken to be a value <0.70 means that some components of the measurements do not contribute to the outcome of interest and may be measuring an unrelated concept. The presence of a very high internal consistence taken to be a value of >0.90 could also be detrimental as a measurement may only be recording a narrow component of the interested item (Streiner, 2003). All of the tests had a test re-test reliability available. For the go-no go task, the omission and commission errors were the more reliable (>0.70) and the reaction time was the least reliable measure of impulsivity (0.63). The Stop signal reaction time also had a good test re-test reliability (0.72). For the Stroop Task, the additional time taken to name the ink colour in the incongruent relative to the congruent condition was shown to have a low test re-test reliability (0.46). However, the test re-test reliability was much improved for times presenting incongruent-neutral conditions (0.73) and for tests measuring the reaction time to incongruent stimulus (0.79-0.87). The internal consistency was not available for all the various components of the inhibitory task test and for the Stop Signal Task the reliability scores have been obtained in studies in children and may be different in the adult population.

Table 2

Reliability and Internal Consistency of Commonly Used Behavioural Measures

Measure	Test re-test reliability	Internal consistency	Studies
Go-no go task	0.09[d]	0.73-0.95[a]	Schweiger et al. (2007)
Omission errors	0.72[d]		
Commission errors	0.76[d]		
Reaction time	0.63[d]		
Stop Signal Task			Friedman et al. (2009)
SSRT	0.72[d]	0.75[b]	
Stroop (single stimulus)			Friedman et al. (2009)
Incongruent-congruent	0.46[c]	0.87-0.88; 0.91	
Incongruent-XXXX	0.73[c]		
RT to incongruent	0.79-0.87[c]		

a Cronbach alpha; ***b*** split half reliability; ***c*** correlation; ***d*** Interclass Correlation Coefficient

3.3. Distinguishing obese from non-obese subjects

Ten studies looked at the relationship between BMI and inhibitory control. Most studies did this by means of a direct cross-sectional comparison between obese and normal weight individuals. The first study found that impulsivity as measured by the error rates on the go-no go task did not significantly differ between the age groups, when they were divided into seven categorical factors between 8 to 15 years-old (Pauli-Pott et al., 2010). However, the difference in error rates reached statistical significance when using a stepwise regression. Here, the body weight was the independent variable against which impulsivity and age were added to the regression. Therefore, age moderated the relationship between impulsivity and body weight. The higher the age-related BMI, the greater the impulsivity scores. This relationship was found particularly in those 11 years-old or younger and not in adolescents. Two further studies using the go-no go task in adults have found no association between measures of impulsivity and weight. The first study (Loeber et al, 2011) tested food-related words versus object words and found that both obese and normal weight groups were faster at responding to go-trials with food compared to go-trials with objects as the target category. There were also no differences between both groups in omission or commission errors (Loeber et al, 2011). Ratcliff (2010) correlated the error rates from the go-no go task against the percentage of body fat in 264 college freshman of whom 63 were clinically obese and found no relationship.

Three of four studies using the Stroop Task found a difference in performance between obese and normal weight adults. Both studies that showed a difference between obese and normal weight participants used non-food related stimulus. Allan and colleagues (2010) used the difference in response time to an incongruent colour-coloured word (e.g. the word blue printed in red ink) and a coloured patch and found that poorer performance on the Stroop test was associated with greater chocolate consumption and higher Stroop scores were significantly associated with higher BMI. Gunstad (2007) used a Verbal Interference test in which the total number of correct responses on a colour-word condition was the measure of inhibitory control. Using a MANCOVA, BMI effects were shown on verbal interference; those who were obese or overweight underperformed in comparison to normal weight individuals. Phelan and colleagues (2011) found that the use of food-related words were able to differentiate obese individuals from normal weight participants by their significantly faster reaction times to high-caloric foods. This particular study also tested participants who had managed to maintain their weight loss for greater than three years. Such weight loss maintainers were found to have the slowest reaction time to high caloric foods of all three groups. The final study to show a difference in impulsivity between obese and normal weight individuals used the Stop Signal Task. Nederkoorn (2006) used the Stop Signal Paradigm with both an auditory and non-food related visual stop cues to differentiate between obese and normal weight adolescents (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006). The same also differentiated between obese and normal weight women again using the SST. However, the difference in task performance was only evident on the fourth and final block of tests. This supports the notion of greater mental fatigue in this group and may be in line with the theory of 'ego depletion' (Baumeister, Bratslavsky, Muraven & Tice, 1998). In this theory, self-control is viewed as analogous to a muscle. With greater use, one's cognitive become fatigued resulting in impulsive acts.

3.4. Inhibitory control as a predictor of increased food intake

Food intake was investigated in three studies using a bogus food test. Studies of food intake compared inhibitory control with other concepts of executive control. Jansen and colleagues (2009) studied the role of inhibitory control in those who were considered to be high-restrained eaters as measured by the Restraint Scale (Herman & Polivy, 1980). Dietary restraint is often found in dieters. Those who are simultaneously high in restraint and in impulsivity overeat due to the lack of inhibition, leading to a failure in attempts at weight loss. Often this loss of self-control can be induced experimentally and *in vivo* in response to influences such as emotional distress, intoxication or a pre-load of food (Heatherton, Polivy, & Herman, 1990). The study found that highly restrained eaters would only overeat in response to a pre-load if they were also highly impulsive (determined by a median split, SSRT 171.2). There is no agreed value for what is the expected value for defining impulsivity using the SSRT. Guerrieri and colleagues (2007) using a slightly lesser median split of 159.4, found that there was no difference in food intake between high and low-impulsiveness in a group of adult females.

Hofmann and colleagues (2008) studied the interaction inhibitory control plays between attention and affect regulation on automatic affective reactions when consuming candy. The underlying principle being that impulses are assumed to contain an affective, hedonic component (Metcalfe & Mischel, 1999) and affect regulation represents the down-regulation of the hedonic affect contributing to the impulse control. It is thought that individuals who can spontaneously down regulate their affect linked to certain foods may be less prone to impulsive eating behaviours. Attention was measured using a simple arithmetic common operation span task and affect regulation was measured by using a modification of the Affect Misattribution Procedure (AMP; Payne et al., 2005). In this task, a non-food related positive or negative stimulus was presented before a neutral Chinese pictograph. One would expect more positive judgement results when Chinese targets characters were preceded by positive primes. The difference in individual evaluation between the positive and negative primes was used as an indicator of affective reactivity to these stimuli. In order to access the temporal decay of affect regulation, a delay between the prime and neutral pictograph varied between the standard 100ms to at 1000 ms. The down regulation of affective reactions over time was measured by the difference in affective reactivity between positive and negative prime trials. A regression using the candy consumption as the dependent variable found that, for those who scored low in inhibitory control, affective reactions played a larger impact on candy consumption.

3.5. Inducing impulsivity using inhibitory control tasks

The relationship between obesity and impulsivity are associations inferred through correlations. The process of inducing impulsivity attempts to prove causality. Houben (2011) demonstrated reduction in food intake following the priming of inhibitory control compared to a group primed to be impulsive. The authors paired food related cues with the stop and go-trials of the Stop Signal Task, in order to manipulate food intake during a bogus food task. In the inhibitory control manipulation, one type of food would consistently be paired with a stop signal, therefore, responses to this type of food would have to be consciously inhibited by the participant. In the impulsivity manipulation, one type of food would never be accompanied by a stop signal and therefore would always be reacted to impulsively by the participant. In the control arm, foods were presented with the stop signal only during half the trials. The three different foods would then be offered to the participants for tasting to determine consumption. Three key findings arose from this study: inhibitory manipulation reduced food intake in a group of participants known to have low inhibitory control (higher impulsiveness) at baseline to levels similar to participants with high inhibitory control. Similarly, for those with the good inhibitory control at baseline, impulsivity manipulation increased consumption of the go-food to the level of those with low inhibitory control. Guerrieri and colleagues (2009) also induced impulsivity using the SST in dieters and non-dieters; sub-divided into those with high and low restraint. Results of the induction of impulsivity and inhibition were in the expected direction with regard to food intake. However, in participants who claimed to be current dieters on the day of testing showed the opposite relationship between their induced state of impulsivity and food intake based their restraint status.

Current dieters in the impulsivity condition had a significantly lower caloric intake compared to the current dieters in the inhibition condition. Once again the finding that current dieters increased their caloric intake in response to the inhibition induction supports the ego-depletion model of self-control. The current dieters were already engaging their self-control on their diet and likely to be in a state of cognitive depletion. Therefore, further acts of self-control would have overwhelmed their system, leading to disinhibition. On the other hand, in the impulsivity induction there was no need to use any cognitive restraint and these participants still maintained their self-control when faced with tasty treats.

3.6. Inhibitory Control as a predictor of weight change

The Stop Signal Task has been shown to be a predictor of weight change in both adolescents and adult females. In a study of normal weight female adults (Nederkoorn et al., 2010), those who were found to have an implicit preference for snack foods, as ascertained by an Implicit Association Task; the SSRT was shown to be a predictor of weight loss at one-year follow-up. Those adults with poorer inhibitory control lost less weight at follow-up. The authors found the same relationship in obese adolescents attending a 1-year residential weight camp programme using a simple correlation of the SSRT against the percentage reduction in BMI (Nederkoorn et al., 2006).

3.7. Inhibitory control and the intention-behaviour gap

If healthy weight-related intentions are to have a direct impact on health and weight, they must be successfully translated into action. This deficit between our good intentions and actions is termed the *intention-behaviour gap* (Allan, 2008*)*. Less than a quarter of people who embark on a healthy eating plan are still sticking to it 12 months later (Dansinger, Gleason, Griffith, Selker, & Schaefer, 2005). Allan and colleagues (2010) studied the role of inhibitory control using both the go-no go task and Stroop Task in predicting the intention-behaviour gap for two key dietary behaviours: eating fruit and vegetables, and high calories snacks. A group of 50 university students quantified their intentions for these behaviours and then kept computer diaries to actually report their behaviour over a 24-hour period. It was found that the number of snacks consumed correlated significantly with performance on the Stroop Task. Therefore, those with weaker inhibition had a larger intention-behaviour gap for snacks than those with stronger inhibition (Allan et al., 2010).

4. Discussion

The available evidence supports the contributory role of executive function in the aetiology of obesity inhibitory control. However, the association between behavioural measures of impulsivity and obesity may not be likely to be representative of the population as experimental groups are often students of normal weight, female or adolescents. The adolescent population is a tentative population as the level of impulsivity as a whole is rapidly changing. The prevalence of obesity between men and women are thought to be equal, however, 8% of women are thought to be morbidly obese in comparison to only 4% of women (National Health and Nutrition Examination Survey, 2013). Women are more likely to seek weight loss treatment on their own or be more likely to be referred by a physician for weight loss management than men (Thande, Hurstak, Sciacca, & Giardina, 2009) which likely explains the large number of groups using this population for their studies. However, one must err on the side of caution with extrapolating findings from normal weight women to obese individuals. As there has been shown to be a difference between normal weight and obese females using a temporal discounting task (Weller, Cook, Avsar, & Cox, 2008).

The development of tasks to specifically study eating behaviour has led to studies integrating food related constructs with impulsivity. An example of this is the combination of the motivation for food into the Stroop resulting in the Food Stroop. The Food Stroop is able to predict weight change and differentiate weight loss maintainers from an obese group of participants unable to maintain weight loss. However, the task performance does not correlate with current BMI. This is a trend seen with most measures of inhibitory control. Despite being able to differentiate between obese and non-obese groups performance sees no correlation with BMI. The sample size of studies may account for this finding. All three of the tests used in the studies identified in this review claim to measure inhibitory control. The stop signal reaction time is calculated by the latency in the stop signal delay (time between the go and stop signal) and the mean reaction time for correct go trials. Therefore, individuals who are able to wait for a delayed stop signal and respond faster to correct go-trials will have a lower SSRT time and therefore have better inhibitory control. This concept seems to capture response inhibition directly. Whilst parameters used from the go-no go task test singular measures that tap a similar construct, with a varying relationship with maladaptive eating behaviours. For example, Hall and colleagues (2012) have shown a significant effect linked to the go reaction time. The go reaction time is unlikely to capture inhibitory control and it is more likely to be an indicator of attention or alertness.

In summary, this review highlights for the first time the role of inhibitory control on obesity, and highlights the need for a better understanding of the mechanisms behind this connection. Performance tasks that measure inhibitory control are able to differentiate between obese and non-obese groups. However, the results may not be likely to be representative of the population as experimental groups are often students of normal weight, female or adolescents. So, it is recommended to use a wider population range and larger samples in future studies.

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Appendix

Behavioural Tasks and Their Measurable Outcomes.

A Table with a summary of Behavioural Tasks and Their Measurable Outcomes

Task Name	Manipulations	Main dependent variable(s)
Stop Signal Task	The SST consists of GO and STOP trials. During the go-trials, the letter O or the letter X is presented for 1000 ms on the centre of a computer screen, preceded by a 500 ms fixation point, also in the centre of the screen. The participant learns to press the button on the right side with the right hand when the X is presented and the button on the left side and with the left hand when the O is presented. The instruction during this choice reaction time task is to press the button as fast as possible. A crucial element of the task is that this learned response has to be inhibited during stop trials. During stop trials a stop signal, a computer-produced 100 ms 1000 Hz tone, is presented. The participant is instructed not to respond when she hears the tone. Between trials, the screen is blank for 1000 ms. Initially, the delay between the go signal (X or O) and the stop signal is 250 ms. Depending on the responding of the participant, a tracking procedure adapts the go–stop delay dynamically; if the participant succeeds in inhibiting the response, the go–stop delay is increased by 50 ms, thereby making it more difficult to inhibit the next trial. If the participant fails to inhibit the response, the go–stop delay is decreased by 50 ms, thereby making it easier to inhibit the next trial. The SST is designed to enable participants to inhibit 50% of the stop trials.	The stop-signal reaction time (SSRT), which is the estimated latency of stopping (Logan & Cowan, 1984). Longer SSRTs usually mean poorer inhibitory control. Invalid reactions can also be assessed.
Go-no go task	Participants are instructed to respond as quickly as possible to go stimuli (e.g. digit) but then to refrain from responding when a no-go stimulus is presented (e.g. letters). Go events usually occur with higher frequency than no-go events.	Responses to distractors (commission errors, i.e., failing to respond to target words).

Implicit Association Test (Greenwald, McGhee & Schwartz, 1998)	The IAT measures the strength of evaluative associations towards different concepts. In the study of Nederkoorn and colleagues (2010), the target category was food, and the attribute/ evaluative categories were "I like" and "I don't like." Evaluative stimuli were six positive and six negative pictures from the IAPS. The target stimuli were six food pictures, depicting a bag of crisps, chocolate, chocolate chip cookie, French fries, a hamburger and a pizza. The participant first completed a practice block in which only negative and positive pictures had to be categorized. In the next block, the first combined block (72 trials in a fixed random order) the participant had to respond to the positive category and food with one response key and to the negative category with the other response key. This assignment was changed in the second combined block such that the negative category and food shared a response key.	Response-latency measures, which involve the measurement of the time delay that occurs before a response (Average median reaction time).
Stroop Test (Golden, 1994)	This test consists of three forms, each containing 100 elements. The first form is made up of the words "RED", "GREEN," and "BLUE" ordered randomly and printed in black ink. In this condition, participants are asked to read aloud the words written. The second form consists of strings of "XXXX" printed in red, blue, or green ink. In this condition, participants are asked to name the color. The third form introduces the condition of interference, and it consists of the words from the first sheet printed in the colors of the second. In this condition, participants have to name the color of the ink and ignore the word.	Verbal interference Incongruent-Neutral RT