Assessing the Relationship Between Cognitive Control and Weight Control

by

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DEDICATION

Dedicated to my family.

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ABSTRACT

Obesity is a complex phenomenon with multiple causes, potentially including cognitive factors. Theories of cognition and obesity have typically focused on executive functions, broadly defined, and findings have been somewhat inconsistent across studies. Here we focus on a new hypothesis about one potential core cognitive issue in obesity: cognitive control difficulties. The central idea motivating this research is that efficient cognitive control is critical to effective weight control. Specifically, vulnerability in the capacity to resist distraction during demanding cognitive tasks may be related to weight regulation difficulties. Moreover, such vulnerability may be specific to situations in which control over food-related distraction is required. Here we assess cognitive control in working memory and sustained attention by examining the resistance to task-intrinsic distraction in working memory tasks, and task-extrinsic distraction in sustained attention tasks. In particular, we use a modified item-recognition working memory task (a semantic variant of the recent-probes task), as well as list-based directed ignoring and directed forgetting tasks to assess the removal of task-intrinsic distraction from working memory. We use signal-detection vigilance tasks with and without distraction to assess the control of sustained attention in the presence of task-extrinsic distraction. We find that overweight/obese participants demonstrate specific cognitive control vulnerability in resisting different types of distraction, in the contexts of managing the contents of working memory and maintaining focused attention. Specifically, overweight/obese individuals show increased food-related semantic interference from task-intrinsic information in working memory relative to their lean peers, increased food-related proactive interference from task-intrinsic information in working memory relative to food-neutral proactive interference, and poorer performance in the presence of task-extrinsic distraction in sustained attention. However, the content-specificity of these effects varied. In the working memory domain, interference was only increased when overweight/obese participants were required to control distraction from food-related information. Conversely, in the sustained attention domain, there was no evidence of such content-specificity. Results concerning other weight-related variables such as dieting and restrained eating are also considered, though the results concerning these variables were less consistent. Taken together, these findings suggest a relationship between cognitive control in the form of resistance to distraction and weight regulation, though the causal direction of this relationship remains unclear. Future studies will build toward a comprehensive research program examining neurocognitive correlates and causes of obesity, and potentially cognitive training interventions to support weight loss.

CHAPTER I

Introduction

Rates of obesity have climbed steadily during the past several decades, and now more than two thirds of adults in the United States are overweight or obese, while more than one third are obese (Flegal, Carroll, Kit, & Ogden, 2012; Ogden, Carroll, Kit, & Flegal, 2012). This pattern of rising overweight and obesity rates is replicated in many first world countries (Stroebe, 2008). Perhaps as a result of climbing obesity rates, a multi-billion dollar diet industry has emerged, with the global market for weight loss and diet management products valued at over $30 billion per year, including only diet foods and drinks, weight loss drugs, natural therapies for weight loss, surgical interventions, and weight loss programs, with additional value generated from gym memberships, fitness clothing, personal fitness equipment and training, and other products or services (Elder, 2009; Porjes, 2013). A variety of weight loss approaches have shown significant results in randomized controlled trials, including behavioural interventions (e.g., Barte et al., 2010; Curioni & Lourenço, 2005; Felix & West, 2013; Glenny, O'Meara, Melville, Sheldon, & Wilson, 1997; Tsai & Wadden, 2005). However, the long term data on weight loss maintenance are mixed. Many dieters are able to achieve success in losing weight in the short term. For example, in a large, representative sample of overweight adults in the United States, 40% of dieters were able to lose at least 5% of their body weight and 20% lost at least 10% of their body weight in one year (Nicklas et al., 2012). However, other data indicate that only about 20% of overweight individuals are able to maintain at least a 10% weight loss for at least 1 year (Wing & Phelan, 2005; see also Barte et al., 2010 for a review). There is also a documented lack of correspondence between strategies effective for successful weight loss versus successful weight maintenance (e.g., Sciamanna et al., 2011). Given the rise in obesity rates and the mixed success of weight loss interventions, questions remain about how to prevent obesity and how to treat obesity to achieve long-term weight loss maintenance.

Interest in the relationship between cognition and obesity has increased along with the increase in medical concern about obesity. A Web of Science search shows that the overall number of papers with "obesity" in the title grew from two in 1920 to more than 5000 published in 2013. A search for papers containing the words "obesity" or "overweight" and "cognitive" or "cognition" in the title shows that the number of papers has gone from just one in the mid 1970s to more than 30 published in the last year. More impressively, the number of times these articles have been cited has jumped from less than 40 in 2003 to more than 500 in 2013. Though it is clear that the fraction of these papers dealing directly with cognition and obesity is still very small, the growing interest reflects increased focus on the hypothesis that there may be a cognitive contribution to the development of obesity, the ability to lose weight, or the ability to maintain weight loss. Food-related thought, focusing on dieting goals and rules, ignoring temptation, and controlling responses to food stimuli are all cognitive components of eating or dieting behavior, prompting questions about the role of cognitive processes in weight management. In particular, are there cognitive functions important to the ability to prevent weight gain or maintain a healthy weight? Are there cognitive processes that can improve the ability to stick to a diet and maintain long-term weight loss? And are there cognitive consequences of carrying excess body weight? This dissertation explores these issues, particularly as they relate to cognitive control processes.

Smith and colleagues (Smith, Hay, Campbell, & Trollor, 2011) reviewed the literature on obesity and cognition, finding relatively consistent effects of weight group in between-group comparisons of normal weight and overweight or obese participants. Categories of normal weight, overweight, and obese are defined using body mass index (BMI), which is a proxy measure of body fat calculated as a ratio of weight to height in kg/m^2. Normal weight is defined as a BMI between 18.5 and 24.9, overweight between 25 and 29.9 and obesity as 30 and above. Smith and colleagues reviewed evidence of global cognitive deficits in obese individuals, as well as specific effects in motor control, language, memory, and executive function across the lifespan. Strikingly, the most robust effects were in the executive function domain. Executive functions are responsible for performance in a variety of higher level cognitive domains, but the term "executive function" is often used broadly, applied to different constructs or exemplars, and assessed using tests which may tap more than one executive ability. Though this dissertation focuses on probing weight effects in executive function, the studies described herein aim to do so with a narrower focus, targeting one candidate ability or set of abilities that may be linked to obesity. In particular, the focus is on examining the role of cognitive control, especially in resisting distraction, as one component of executive function that may be related to weight control.

Cognitive control can be defined as the "ability to configure [the human cognitive system] for the performance of specific tasks through appropriate adjustments in perceptual selection, response biasing, and the on-line maintenance of contextual information" (Botvinick, Braver, Barch, Carter, & Cohen, 2001, p. 624). That is, when confronted with changing task conditions or priorities, cognitive control allows us to reconfigure our attention, response selection, and goal-maintenance in order to accurately and efficiently perform a given task. For example, if the system is tasked with identifying the colour of a stimulus, and subsequently receives instruction to identify size or shape instead, the system needs to be able to adjust the stimulus dimension to which attention is focused, change the criteria being used to select responses, and maintain the new task rule in mind. Examples of contexts in which cognitive control is necessary for good performance are the effective regulation of attention and working memory. In order to achieve effectual control of attention or working memory, one must be able to resist distraction, whether it is task-relevant or irrelevant, whether it is internal or external in its source, and whether it is intrinsic to the task itself, or task-extrinsic. There is some controversy regarding the use of the terms executive control, executive function, cognitive control, and working memory—whether these terms may be used interchangeably or refer to dissociable constructs is debated. In this chapter and those that follow, we consider cognitive control to be a set of processes to do with the allocation of attention. In using such a definition, we may consider executive functions to be collections of cognitive control processes, and we may examine the cognitive control processes of working memory and sustained attention.

Distraction is usually conceptualized as an externally-driven, task-extrinsic experience. For example, a salient stimulus might capture attention in a bottom-up manner. Alternatively, distraction may be thought of as an internally-driven process. Internal representations may capture attention or divert processing resources away from a central task in a similar fashion. For example, rumination, in which people rethink about something or dwell on a negative experience, can be construed as an example of an internal representation distracting from a task at hand, and has been linked to poor task performance (e.g., Berman et al., 2011). Additionally, mind-wandering during task performance can be driven by internal representations guiding attention and thought rather than being triggered by external events, as in self-directed thinking.

Previous research on distractibility and obesity has focused almost exclusively on external distraction, for example auditory distraction and the relationship between distraction and external cues that may contribute to overeating (i.e., external eating; Herman, Polivy, Pliner, Threlkeld, & Munic, 1978; Rodin, 1973; Schachter, 1968).

Though this type of distraction is certainly known to provoke worse performance than conditions of no distraction, external distraction is not the only way in which distractibility may influence performance. In particular, many tasks include the opportunity for what will be termed task-intrinsic distraction. That is, when stimuli that are part of the main task to which participants are meant to be attending inappropriately remain in attention or memory, they may cause interference—one type of distraction. If once-relevant information is not discarded, suppressed, ignored, or otherwise overwritten by newly relevant information, performance can be impeded. This is substantially different from what will be termed task-extrinsic distraction, wherein stimuli that have no bearing on regular task performance come to interfere with, or otherwise distract from optimal task engagement and performance.

The scientific aims of this dissertation are to address the following questions: 1) is obesity associated with increased vulnerability to task-intrinsic and/or task-extrinsic distraction and 2) are these distraction effects more pronounced when content is food-related? These two aims are assessed in the following chapters in two cognitive domains: working memory and sustained attention. Working memory is a system which allows us to retain and manipulate small amounts of information over short time periods, and is central to many higher level cognitive operations. Working memory was selected because a disruption in its function is potentially devastating for numerous other cognitive abilities, as it is a foundation for many higher functions. Determining whether obesity is associated with disruption in this system is therefore of paramount importance. Sustained attention is one important facet of the human attentional system, enabling the maintenance of alertness. Though it is distinct from other types of attentional control, sustaining focus over long periods of time is an important enabler of selection, discrimination, and response execution. Thus, disruptions in control of sustained attention could also throw many other attentional mechanisms off course.

The chapters that follow assess the vulnerability of working memory to task-intrinsic distraction using a number of item-recognition tasks, including the recent-probes task (Chapter II; Jonides et al., 1998; Monsell, 1978), and directed forgetting and directed ignoring tasks (Chapter III; Nee & Jonides, 2008; Nee & Jonides, 2009). Finally, the vulnerability of sustained attention to task-extrinsic distraction is assessed using modified versions of the Sustained Attention Task and its distractor condition (Chapter IV; Demeter, Guthrie, Taylor, Sarter, & Lustig, 2013; Demeter, Hernandez-Garcia, Sarter, & Lustig, 2011; Demeter, Sarter, & Lustig, 2008). In each cognitive domain, food-neutral and food-related distractors are used, with a variety of stimuli and modalities employed. This dissertation thus assesses the hypotheses that overweight/obese individuals are more susceptible to task-intrinsic distraction in working memory than their lean peers; that overweight/obese individuals are more susceptible to task-extrinsic distraction in sustained attention; and finally, that this susceptibility is only significant when distraction is food-related.

By documenting the results of experiments assessing these hypotheses, this dissertation aims to show that any claims of stimulus-general and widespread cognitive deficits in obesity should be re-evaluated and potentially limited to certain task contexts or populations, and that hypotheses about cognitive correlates of obesity should be specified and narrowed. Increasing the specificity with which cognitive processing in obesity is studied will allow a more precise characterisation of the types of processes that may contribute to obesity or may be disrupted as a result of carrying excess weight. Only when any cognitive issues associated with obesity are specifically defined can questions about mechanisms, causal attributions, and potential interventions be fruitfully explored.

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CHAPTER II

Implicit Task-Intrinsic Distraction in Working Memory

Introduction

As the incidence of obesity has increased in the past several decades (Ogden, Carroll, Kit, & Flegal, 2012), there has also been an increased interest in potential cognitive contributions to the development of obesity and the ability to lose weight or maintain weight loss. Food-related thought, focusing on dieting goals and rules, ignoring temptation, and controlling responses to food stimuli are all cognitive components of eating or dieting behavior, prompting questions about the role of cognitive processes in weight management. In early reports, one potential cognitive issue identified in obesity was an apparent tendency to be more responsive to external stimuli (e.g., Rodin, 1973; Schachter, 1971; Schachter & Gross, 1968), including increased levels of response to off-task distractions such as stories presented in the auditory modality during a visual reaction time task (Rodin, 1973). Though this increased distractibility has been replicated (e.g., Pliner, 1976; Rodin & Slochower, 1976; Rodin et al., 1977a; Rodin, Slochower, & Fleming, 1977b) and has been shown to be exaggerated when the distraction is interesting or emotional (e.g., Rodin, 1973), previous studies have not established whether or not food-related distraction was differentially effective in producing performance decrements. Thus, existing evidence (e.g., Rodin, 1973, Schachter, 1971) has suggested increased distractibility exists in overweight or obese individuals quite generally.

Though generalized cognitive difficulties such as those mentioned above are intriguing, BMI is the result of a number of factors, including food consumption, which means that there may be some cognitive marker of excess consumption behaviour in the form of increased attention to food or food-related thought. If individuals who are overweight or obese are more susceptible to food-related intrusive thoughts or food-related attentional capture, for example, there should be some evidence of this increased distractibility that is specific to food-related distractors. One notable variant of a food-specific distractibility effect is the substantial body of evidence indicating that when palatable food acquires incentive salience, individuals can become very sensitive to food-related cues (e.g., Berridge, 1996; 2007) and this type of food-cue sensitivity and disturbances in the reward system more generally could contribute to overeating or obesity (e.g., DiFeliceantonio, Mabrouk, Kennedy, & Berridge, 2012; Ferriday & Brunstrom, 2011; Gearhardt & Potenza, 2013; Volkow, Wang, Fowler, & Telang, 2008; Volkow, Wang, & Baler, 2011). Such sensitivity to food-related information as a result of acquired incentive salience would also suggest that food cues should be distracting, and perhaps more so than other types of distraction. However, to our knowledge, cognitive evidence of such food-specific distractibility in obesity is generally lacking, though previous research has shown some indication of a heightened food-related attentional bias (e.g., Castellanos et al., 2009; Gearhardt, Treat, Hollingworth, & Corbin, 2012; Hou et al., 2011; Meule, Lutz, Vögele, & Kübler, 2012; Yokum, Ng, & Stice, 2011; but see Loeber et al., 2012).

Thus far, research on cognitive performance in obesity has established a fairly consistent finding of impaired executive functioning (see Smith, Hay, Campbell, & Trollor, 2011 for a review). Executive functions are processes that allow flexible responding to changing task conditions, and are critical for higher cognitive performance. Previous experiments have assessed executive control broadly defined, often using a single task (e.g., Stroop) to assess executive functioning. However, modern theories of executive control posit multiple, coordinated functions rather than one ability. Many theories of executive function posit a function or functions involved in resisting distraction, conflict, or interference (e.g., Aron, Robbins, & Poldrack, 2004; Johnson, Raye, Mitchell, Greene, & Anderson, 2003; Logan, 1985; Miyake et al., 2000; Shallice & Burgess, 1996; Smith & Jonides, 1999), reflecting the importance of controlling responses to distraction in effective executive functioning.

When studies have specifically assessed distractibility as an index of executive control failure, they have focused on task-extrinsic distraction, meaning distraction external to the task at hand. In fact, distraction is most often conceptualized as an externally-driven experience. For example, a salient stimulus in the environment might capture attention in a bottom-up manner. Researchers have presented such distraction in a different modality from the main task, and have varied distraction in meaningfulness from nonsense syllables to highly emotionally salient information. Focus has been on the relationship between distraction and external cues that may drive overeating (i.e., external eating; Herman, Polivy, Pliner, Threlkeld, & Munic, 1978; Nijs, Franken, & Muris, 2009; Rodin, 1973).

In the present experiments, we focus on a different type of distraction, namely task-intrinsic distraction, as distraction may also be thought of as an internally-driven process. Specifically, internal representations may capture attention or divert processing resources away from a central task. For example, rumination, in which people dwell on a negative experience, can be construed as an example of an internal representation distracting from a task at hand, and has been linked to poor task performance (e.g., Berman et al., 2011; Joormann, Nee, Berman, Jonides, & Gotlib, 2010). Additionally, mind-wandering during task performance can be driven by internal representations guiding attention and thought rather than being triggered by external events, as in self-directed thinking. We assess the hypothesis that overweight and obese individuals are more susceptible to such internal distraction, particularly when the distraction is food-related.

Though it is not clear whether carrying excess weight might result in food-related distractibility, or whether this cognitive feature would pre-dispose someone to gain weight, it is possible that such distractibility would not be exclusive to weight *per se*. In particular, if someone has other reasons to be very focused on food, they could show a similar sensitivity to food-related distraction. In particular, individuals who are dieting to lose weight or restricting their food consumption for fear of gaining weight may devote additional cognitive resources to their food choices. Such individuals may also find themselves thinking longingly about forbidden foods or planning their next meal. Previous research has shown that restrained eating and dieting behavior may be associated with higher BMI (Herman & Polivy, 1980; Snoek, van Strien, Janssens, & Engels, 2008; de Lauzon-Guillain et al., 2006). In fact, dieting behavior generally, and restrained eating specifically, have been associated with a number of cognitive effects (e.g., Brooks, Prince, Stahl, Campbell, & Treasure, 2011; Hollitt, Kemps, Tiggemann, Smeets, & Mills, 2010; Papies, Stroebe, & Aarts, 2009; Ward & Mann, 2000) including reduced working memory capacity and general distractibility (e.g., Green, Elliman, & Rogers, 1997; Green & Rogers, 1998; Herman et al., 1978; Shaw & Tiggemann, 2004).

Distraction and Working Memory

We assess hypotheses regarding obesity, dieting, and task-intrinsic distraction below, in the context of working memory task performance. Working memory is a system which allows us to retain and manipulate small amounts of information over short time periods. Working memory is central to many higher level cognitive operations, such as planning and problem solving (e.g., Ricks, Turley-Ames, & Wiley, 2007; Süß, Oberauer, Wittmann, & Wilhelm, 2002), and it has been shown to influence important higher level functions such as reading comprehension (e.g., Daneman & Carpenter, 1980) and fluid intelligence (e.g., Buschkuehl et al., 2008; Engle, Tuholski, Laughlin, & Conway, 1999).

There is reason to hypothesize that working memory would be one function implicated in a cognitive profile of obese individuals. First, there have been reports of altered prefrontal cortical activity and structure in overweight and obesity (e.g., Brooks et al., 2012; Gonzales et al., 2010; Skibicka & Dickson, 2011; Volkow, Wang, Fowler, & Telang, 2008; Willeumier, Taylor, & Amen, 2011). There have also been previous reports of altered activity in frontal and parietal regions from functional neuroimaging measures during working memory tasks in overweight and obese individuals (Gonzales et al., 2010; Stingl et al., 2012). However, these tasks either found no impairment in working memory performance, or impoverished performance relative to normal weight controls regardless of whether the task contained food information or not. Additionally, these tasks were not constructed to assess distractibility and so cannot evaluate the hypotheses addressed in the present experiments. Finally, previous evidence of attentional biases to food-related information also suggests that working memory could be impacted in obesity, as an attentional bias could affect the contents of the focus of attention or region of direct access in working memory, leading to impaired performance when such information interferes with processing necessary to the task.

As mentioned above, working memory is critical to higher thought processes, and is conceptualized as a foundational ability for other types of executive control and processing. Working memory is necessary, for example, in order to be able to read this sentence from start to finish and to enable the extraction of its meaning. Working memory is a system that processes all types of information in all types of cognitive settings, so a disruption in its function is potentially devastating for numerous other cognitive abilities. For this reason, it is important to determine whether this system is vulnerable to disruption in obesity.

Though there have been several proposed models of working memory and the cognitive operations involved in the short term maintenance and activity of information in mind, modern conceptions of working memory posit a focus of attention that is capacity limited and contains only the most currently active information, as well as a region of potentially activated representations and/or active long-term memory representations (e.g., Cowan, 2001; Oberauer, 2002; see Jonides, Lewis, Nee, Lustig, Berman, & Sledge-Moore, 2008 for a review). Oberauer's (2002) model, for example, describes a focus of attention containing the item on which cognitive processing is currently occurring, a region of direct access containing representations that form the set from which subsequent selection for processing occurs, and activated information in long-term memory, which can bias the processing carried out in the focus of attention. If representations irrelevant to current task performance gain access to the region of direct access or focus of attention, it could result in off-task processing—distraction. Similarly, if certain long-term memory representations are passively activated by off-task distractors, they could potentially bias processing in an off-task direction, again resulting in increased distraction from the task at hand.

For example, consider a case in which distracting information gains access to the region of direct access or focus of attention—since these components of working memory are capacity-limited, normal cognitive processing that would be carried out in these components would be disrupted. Thus, if food-related information specifically, or salient distractor information generally, has privileged access to working memory in obesity by virtue of being prioritized or motivationally salient, it would result in susceptible individuals being less able to carry on normal cognitive processing operations.

In the present experiments, we assess the hypotheses that overweight/obese individuals are more vulnerable to distraction, and that this vulnerability is exaggerated in food-related conditions. We also assess the secondary hypothesis that individuals dieting to lose weight are more vulnerable to distraction, especially so when distraction is food-related. We assess these hypotheses in reference to distraction that is intrinsic to the task at hand. That is, we focus on distraction that occurs in the course of normal task performance, as a result of task-relevant stimuli that must be processed or attended in order to effectively perform the main task. This is in contrast to previous reports (e.g., Herman et al., 1978; Rodin, 1973; Schachter & Gross, 1968) in which distraction was task-irrelevant and task-extrinsic.

In order to examine the effects of task-intrinsic distraction in working memory, we focused on the ability to resist interference. There is more than one type of interference that can occur in a working memory task. Proactive interference, for example, can occur when previously relevant information interferes with the ability to keep currently relevant information in mind. Semantic interference occurs when representations which are meaningfully related to the contents of working memory come to interfere with the retention of actual to-be-remembered items. As explained below, working memory task parameters can be manipulated to introduce semantic or proactive interference, thus requiring that one is able to efficiently guard working memory against irrelevant information in order to accurately respond to probe items. The inability to remove irrelevant information from working memory will result in slower responding and/or decreased accuracy on certain trial-types depending on which type(s) of interference is/are being induced.

Recent-probes task

In a typical item-recognition working memory task, subjects are asked to remember four words, and after a short delay, a probe word is presented and they must indicate whether the probe was a member of the set of to-be-remembered words (e.g., Sternberg, 1966). In previous research, this task has been modified to assess how effectively subjects are able to rid their working memory of now irrelevant words from the previous trial. This task is called the recent-probes task (Jonides & Nee, 2006; Jonides, Marshuetz, Smith, Reuter-Lorenz, & Koeppe, 2000; Jonides, Smith, Marshuetz, Koeppe, & Reuter-Lorenz, 1998; Monsell, 1978; Nee, Jonides, & Berman, 2007). As in a standard item-recognition task, subjects view sets of four words to remember over a several-second delay, after which a probe word is presented, and subjects must indicate whether or not the probe came from the set of words they just studied. There are 50% "yes" trials and 50% "no" trials. The "no" trials can be *non-recent* (if the probe item was not presented in the current memory set nor any recent memory set) or *recent* (if the probe item was not present in the current memory set, but was presented in the one just prior). Subjects must control proactive interference created by the recent probes in order to perform the task correctly, and this requires effectively managing the contents of working memory by removing no-longer-relevant items from mind. That is, subjects must rid their working memory of recently presented words in order to correctly respond that recent probes are *not* members of the current set of words even while the items have lingering familiarity due to their recent presentation.

In the present experiments, the recent-probes task has been adapted by including a semantic category manipulation. In Experiment 1, we used two semantic categories modeled after Atkins, Berman, Reuter-Lorenz, Lewis, and Jonides, (2011) as depicted in Figure 2.1. The two categories were food and country names, pitting food-related task-intrinsic distraction against food-neutral task-intrinsic distraction (i.e., distraction from country names). This version of the task allowed the assessment whether food-related information specifically would be most difficult for obese and/or dieting individuals to remove from working memory. In Experiment 2, we used flower and country names, meaning that both categories were food-neutral. This allows the assessment of the hypothesis that in the complete absence of food-related information, there would be no group differences in task-intrinsic distraction.

Experiment 1

Method

Participants. Fifty-six adults between the ages of 18 and 30 were recruited for the experiment, which was described as a "food and cognition" study, and were compensated for their time. One participant was excluded because he had learned English at the age of 10, two participants were excluded for falling outside the inclusion age range, two participants were excluded for previous head injury with loss of consciousness, and one participant was excluded for having a current ADHD diagnosis and taking stimulant medication. These participants were replaced to yield a final sample of 50, with 25 participants in each weight group. Weight groups (normal weight, overweight/obese) were defined by BMI cut-offs. BMI is a proxy measure of body fat calculated as a ratio of weight to height in kg/m^2. Groups were defined such that those in the normal weight group had BMI < 25, and those in the overweight/obese group had BMI ≥ 25. All included subjects were healthy with no reported medical diagnosis or medication that would influence their weight. See Tables 2.1 and 2.2 for participant characteristics.

Materials. Stimuli were 25 food names (4-8 letters in length; mean length = 6.08, median = 6) and 25 country names (4-7 letters in length; mean length = 5.72, median = 6).

Task. The recent-probes task was programmed in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). As in a typical Sternberg item-recognition working memory task, each trial began with an inter-trial interval (ITI) of 2000 ms, followed by the stimulus display of four words that appeared on screen for 2000 ms, followed by a 3000 ms retention interval, and finally a probe item that appeared on screen for up to 2000 ms, and disappeared upon response. See Figure 2.1.

In each trial, four food names or four country names appeared in the stimulus display. The semantic category of the stimuli alternated between food and country (stimulus trial order was either food-country-food-country, or country-food-country-food). Each block contained 48 trials, with 50% of the trials being positive probes. Of the other 50%, half were recent-negative probes, in which the probe did not appear in the stimulus display of the current trial, but did appear in the stimulus display of the previous trial. Note that because of the alternating pattern of stimulus categories, the recent probes were always a category-mismatch for the current stimulus display category. The remaining 25% of trials were non-recent negatives (NRN), which had not been displayed in the previous two trials. Due to the inclusion of two category types, subjects could see two types of non-recent negative probes: probes that matched the current category, and probes that did not. The latter induced no semantic interference, but the former were probes from the same semantic category as the stimulus set, and they potentially created semantic interference.

There were four runs of the task, each consisting of 48 trials, yielding a total of 192 trials, with 48 positive probes of each category, 24 recent-negative probes of each category, 12 non-recent negative matching probes of each category, and 12 non-recent negative non-matching probes of each category. Trial order was randomized for each participant. Each run was separated by a one-minute rest period, during which subjects received performance feedback on their speed and accuracy during the immediately previous run and overall. Each subject completed a brief practice block of four trials containing no words from either of the test categories to familiarize them with the procedure. Subjects were instructed to respond quickly and accurately, and they were told that they would receive a score at the end of the experiment based on speed and accuracy that would be converted to a cash bonus to underscore the importance of quick and accurate responding. Participants were not instructed about the category manipulation, the recency manipulation, or any other task parameters before the task began.

Two interference scores were calculated using reaction times (RTs) for the four probe types described above. First, Mean $RT_{\text{NRN SAME CATEGORY}}$ – Mean $RT_{\text{NRN DIFFERENT CATEGORY}}$ yielded an index of how much people were slowed by the category being the same, ignoring recency (semantic interference). Mean $RT_{\text{RECENT NEGATIVE}}$ – Mean $RT_{\text{NRN DIFFERENT CATEGORY}}$ yielded an index of how much people were slowed by the recency condition (proactive interference). These scores were computed separately for each stimulus type. All RTs were trimmed to exclude any response less than 200 ms. It was hypothesized that overweight/obese individuals would have increased proactive and semantic interference scores, and that these effects would be exaggerated for scores calculated using the food trial RTs compared with the country trial RTs.

Procedure. After completing informed consent and a demographics survey, participants completed the recent-probes task. Following task completion, they filled out a battery of questionnaires, including the Rotter Locus of Control Scale (Rotter, 1966) as a measure of internal versus external control orientation; the Dutch Eating Behaviour Questionnaire (DEBQ; van Strien, Frijters, Bergers, & Defares, 1986), the Restraint Scale (Herman & Polivy, 1975);

1980), and the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) as assessments of eating behaviours and attitudes; personal and family weight history questions to assess individual and familial weight history; the Weight Locus of Control scale (Saltzer, 1982) the Multi-Dimensional Body-Self Relations Questionnaire (MBSRQ; Brown, Cash, & Mikulka, 1990; Cash, 2000) and a version of the Body Image Assessment for Obesity (BIA-O; Williamson et al., 2000; Williamson, Gleaves, Watkins, & Schlundt, 1993) as measures of body image; questions about hunger levels during the experiment, as we did not ask participants to refrain from eating before participation; and a subset of the participants completed the Yale Food Addiction Scale (YFAS; Gearhardt, Corbin, & Brownell, 2009) as an additional measure of food behaviour and attitudes.

Following completion of the questionnaire battery, participants' height and weight were measured, and they completed a post-experimental questionnaire assessing strategy use and perceptions of the experiment. In order to account for some of the inaccuracies in using BMI as a measure of obesity (e.g., a larger, but fit and muscular person might have the same BMI as a person carrying more adipose tissue at the same height), we also included a visual rating measure. Two research assistants covertly rated the adiposity of each participant on a scale from one to ten, with ten being the most adipose. The inter-rater reliability of this measure was .82 in this sample.

Results

Overall Performance

Results were not consistent with a general impairment in working memory in individuals who are overweight/obese—analyses did not indicate differential overall performance. See Tables 2.3 and 2.4 for overall performance data. Specifically, an ANOVA including stimulus type (food vs. place), trial type (positive, recent negative, non-recent negative category match, non-recent negative category mismatch), and group (normal weight vs. overweight/obese) on mean accuracy as an outcome variable yielded no significant main effects or interactions, all $F < 1$, all $p > .4$, except a significant main effect of trial type, $F(3, 144) = 8.13$, $p < .0001$, $\eta_p^2 = .145$. This was due to matching non-recent negatives and positive probes being more difficult than recent negatives, as well as positive probes being more difficult than mismatching non-recent negatives, and matching non-recent negatives being more difficult than mismatching non-recent negatives, all $|t|(49) > 2.4$, all $p < .02$. Though it may seem unusual for positive probes to result in lower accuracy than recent negative probes, the recent negative probes were always from the mismatched semantic category relative to the current stimulus set. Conversely, positive probes were category matched to the current stimulus set, as were some non-recent negative probes. The inclusion of these matching non-recent negative probes likely results in slowed responses to category-matched probes, accounting for the relative difficulty of positive probes documented above.

An ANOVA including stimulus type, trial type, and group with mean RT as an outcome variable yielded a main effect of trial type, $F(3, 144) = 36.63$, $p < .0001$, $\eta_p^2 = .433$, which was driven by recent negative responses being slower than mismatch non-recent negatives and faster than matching non-recent negatives, positive probes being slower than matching non-recent negatives and faster than mismatching non-recent negatives, and matching non-recent negatives being slower than mismatching non-recent negatives, all $t(49) > 4.3$ all $p < .0001$. There was also a stimulus type by trial type by group interaction that approached significance, $F(3, 144) = 2.46$, $p = .066$, $\eta_p^2 = .049$. Planned comparisons showed the only RT difference between groups that approached significance was on food matching category non-recent negative trials, $t(48) = -1.95$, $p = .057$, $d = -.557$[1]. There were no other main effects or interactions, all $F < 1.4$, all $p > .2$.

To analyze the influence of current dieting status on performance, we used responses to one item on the MBSRQ which read “I am on a weight loss diet.” Participants rated their agreement with this item on a scale from one to five. We grouped anyone responding three or higher as current dieters, and the others as current non-dieters. This gave us a sample of 15 dieters and 35 non-dieters[2].

Overall, the dieting results did not indicate a general impairment in working memory in current dieters. An ANOVA on accuracy data including diet group, trial type, and stimulus type, revealed a significant effect of trial type, $F(3, 144) = 9.77$, $p < .0001$, $\eta_p^2 = .169$. The stimulus type by trial type by dieting status interaction was also significant, $F(3, 144) = 3.55$, $p < .02$, $\eta_p^2 = .069$. This three-way interaction was driven by a significant difference between dieters and non-dieters on food non-recent negative match trials, $t(48) = -2.21$, $p = .03$, $d = -.732$, with dieters having lower accuracy than non-dieters. This group difference is evidence consistent with the hypothesis about increased difficulty in the dieting group coping with food-related information. There were no other main effects or interactions, all $F < 2.3$, all $p > .10$.

Analysis of mean RTs revealed a main effect of trial type, $F(3, 144) = 38.26$, $p < .0001$, $\eta_p^2 = .444$, and a trial-type by dieting status interaction that failed to reach significance $F(3, 144) = 2.26$, $p = .08$, $\eta_p^2 = .045$. The stimulus type by trial type by dieting status interaction failed to

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[1] We calculated *d* as the difference between means divided by averaged SDs. Where there were unequal sample sizes, we weighted the average SD calculation by sample size.

[2] It is common in the literature to assess dieting behavior by way of a median split analysis based on restrained eating scores on the Restraint Scale (Herman & Polivy, 1980). When we conducted such an analysis, we found that the pattern of results was not qualitatively different from the current dieting results reported here. However, the results based on Restraint Scale scores were statistically less robust than our chosen measure of current dieting status. Thus, it may be that performance is more closely related to current dieting status rather than a trait-like measure of dieting tendencies, such as is captured by the Restraint Scale and other restrained eating measures.

reach significance, $F(3, 144) = 2.09$, $p < .11$, $\eta_p^2 = .042$. Planned comparisons showed that dieters were marginally slower than non-dieters on food non-recent negative matching probes only, $t(48) = 1.84$, $p = .07$, $d = .582$. All other $p > .3$. There were no other significant main effects or interactions, all $F < 1$, all $p > .4$

Semantic Interference

We conducted a set of ANOVAs including group (normal weight vs. overweight/obese) and stimulus type (food vs. place) on each of the interference score types: semantic and proactive interference. Interference score results indicated evidence of a specific vulnerability to the type of task-intrinsic distractibility induced by the recent-probes task parameters—overweight and obese individuals were differentially vulnerable to interference from food stimuli only, as evinced by the significant difference in food semantic interference scores in the absence of other significant differences. This selective vulnerability to food-related interference was also present for current dieters.

The ANOVA on semantic interference scores yielded no main effect of stimulus type or group, both $F < 1.3$, both $p > .2$, and an interaction between group and stimulus type that failed to reach significance, $F(1, 48) = 3.11$, $p = .08$, $\eta_p^2 = .061$. Planned comparisons revealed that the overweight/obese group had significantly higher food semantic interference scores, $t(48) = -2.05$, $p < .05$, $d = -.597$, but not place semantic interference scores, $t(48) < 1$, $p > .6$, $d = .112$. Within subjects comparisons revealed that neither normal weight participants nor overweight participants showed significant differences between food and place semantic interference scores, both $|t|(24) < 1.6$, both $p > .10$.[3]

[3] Combining accuracy and RT interference data into z-scores for each stimulus type, and using these z-scores as the dependent variable in an ANOVA with group and stimulus type yielded no significant main effects or interactions, all $p > .3$, and no significant planned comparisons, all $p > .2$. These weakened results relative to the RT interference scores are due to a lack of group differences in accuracy measures.

A separate ANOVA on semantic interference scores using the dieting groups revealed a main effect of dieting status, $F(1, 48) = 3.95$, $p = .05$, $\eta_p^2 = .076$, no effect of stimulus type, $F(1, 48) < 1$, $p > .6$, and a stimulus type by dieting status interaction that failed to reach significance, $F(1, 48) = 2.11$, $p = .15$, $\eta_p^2 = .042$. Planned comparisons showed dieters had significantly higher mean food semantic interference scores compared to non-dieters, $t(48) = 2.49$, $p < .02$, $d = .808$, but not place semantic interference scores, $t(48) = 0.39$, $p > .6$, $d = .122$. Within-subjects comparisons revealed that neither dieting nor non-dieting participants showed significant differences between food and place semantic interference scores, both $|t|(24) < 1.1$, both $p > .2$.[4] See Figures 2.2 and 2.3 for interference score data.

Proactive Interference

The proactive interference results did not indicate any group differences in interference for either stimulus category. An ANOVA on proactive interference scores yielded no main effect of BMI group or stimulus type, both $F < 1$, both $p > .4$, and an interaction between group and stimulus type that failed to reach significance, $F(1, 48) = 2.32$, $p = .13$, $\eta_p^2 = .046$. Planned comparisons revealed that no significant differences between groups or within subjects, all $|t| < 1.9$, all $p > .07$. There were no significant main effects or interactions in an ANOVA on proactive interference scores when considering dieting status, all $F < 1$, all $p > .4$.[5]

Correlational Analysis

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[4] Combining accuracy and RT interference data into z-scores for each stimulus type, and using these z-scores as the dependent variable in an ANOVA with diet group and stimulus type yielded a significant main effect of dieting status, $F(1, 48) = 4.54$, $p < .04$, $\eta_p^2 = .086$, no main effect of stimulus type, $p > .3$, and a stimulus type by dieting status interaction, $F(1, 48) = 6.82$, $p < .02$, $\eta_p^2 = .065$. Planned comparisons showed dieting participants to have significantly higher food semantic interference, $t(48) = 3.07$, $p < .01$, $d = .997$, but not place semantic interference, $t(48) = .26$, $p > .7$, $d = .083$. Dieting participants also had significantly higher food compared with place semantic interference, $t(14) = 2.19$, $p < .05$, $d = 0.581$, which was not true of non-dieting participants, $t(34) = -1.43$, $p > .10$, $d = -.241$.

[5] Using combined accuracy and RT interference z-scores for each stimulus type yielded no significant main effects or interactions, and no significant planned comparisons with either group or dieting status as a variable of interest, all $p > .4$.

Though to this point, BMI and dieting status have been treated as dichotomous variables, individuals in fact vary along these variables as continuous dimensions. In order to evaluate the hypothesis that the degree to which dieting and obesity are related to performance on the recent-probes task, correlations were computed between the interference scores and several questionnaire variables of interest. We restricted analysis to several key variables of interest and below we only interpret correlations that reached statistical significance.

Interference scores were correlated with variables from the questionnaire data that were hypothesized to best capture the dimensions of obesity and dieting behaviour. BMI and average participant adiposity ratings were used to reflect the degree to which a participant was overweight. We hypothesized that higher BMI and adiposity ratings would be positively related to food interference scores but not place interference scores. Additionally, item 57 of the MBSRQ, which asked participants to state on a scale from 1 to 5 how strongly they agree with the statement "I am on a weight loss diet," was included as an index of current dieting behaviour. We hypothesized that higher agreement with current dieting would be positively related to food interference scores but not place interference scores. Total scores on the Restraint Scale, and the uncontrolled eating, emotional eating, and cognitive restraint subscales of the TFEQ were used, along with the restraint, external eating, and emotional eating subscales of the DEBQ as indices of long-term dieting and eating behaviour. We hypothesized that restrained eating, indexed by the Restraint Scale and the restraint subscales of the TFEQ and DEBQ would be positively related to food interference scores but not place interference scores. The other TFEQ and DEBQ subscales were included in a more exploratory fashion. We thus correct for the inclusion of these exploratory tests by applying a Bonferroni correction, and only discuss them as significant if they passed the threshold ($p < .00625$). Finally, the overweight preoccupation factor subscale of the MBSRQ was used as an index of how much participants worried about being or becoming overweight. We hypothesized that more overweight preoccupation would be positively related to food interference scores but not place interference scores.

As predicted, several measures of eating behaviour and food-related thought were related to performance on the food and place recent-probes task. Though there were small correlations with objective measures of overweight/obesity, stronger correlations emerged with weight-related worry, dieting, and restraint. These correlations were largely restricted to food-related interference scores.

Food interference scores.

Food semantic interference scores were not correlated with BMI, $r = .16$, $p > .2$, though they were correlated with average adiposity ratings, $r = .28$, $p < .05$. Current dieting status was also correlated with food semantic interference scores, $r = .44$, $p < .002$, as was total Restraint Score, $r = .34$, $p < .02$. Overweight preoccupation correlated with food semantic interference as well, $r = .39$, $p < .006$. None of the TFEQ subscales, nor DEBQ subscales correlated with food semantic interference scores, all $|r| < .21$, all $p > .15$.

Finally, food proactive interference scores did not significantly correlate with any of the variables, all $|r| < .28$, all $p > .06$.

Place interference scores. No significant correlations emerged between any questionnaire variable of interest and place semantic interference, all $|r| < .12$, all $p > .50$. There were no significant correlations with place proactive interference scores, all $|r| < .27$, all $p > .06$.

Discussion

Experiment 1 provided evidence supporting the hypothesis that overweight or obese individuals have increased interference specific to food information in working memory.

Semantic interference in the recent-probes task potentially stems from the failure to control the access of currently irrelevant but task-intrinsic and task-related information to the focus of attention. However, this failure of control was limited to trials on which the information was food-related[6]. The results are thus inconsistent with a hypothesis that overweight or obese individuals have a generalized cognitive control deficit detectable in all contexts.

Interestingly, though the division of participants into normal weight versus overweight/obese yielded significant differences in certain interference score means, these same interference score values did not correlate highly with BMI values. Based on the correlational analyses and the between-groups analyses using current dieting status and restrained eating tendencies, food-related thought and behaviour may also be important in determining vulnerability to task-intrinsic distraction in the recent-probes task. Specifically, the extent to which individuals worry about being overweight, attempt to control or restrict their eating behaviour in order to lose weight, or find themselves vulnerable to external or emotional eating were correlated with performance in the food-related conditions of the recent-probes task. Table 2.1 shows that the overweight/obese individuals score higher on many of these variables. This may indicate that interplay between these factors is important in determining performance.

Despite the evidence from Experiment 1 being consistent with the predictions outlined at the start of this chapter, it remains unknown how general or specific these effects are. Without a control condition involving two non-food categories of items, it is not clear that the food content specifically was responsible for the imbalanced interference effects in the overweight/obese

[6] The reader may be interested to know that we performed a version of Experiment 1 in which we blocked the food and country categories rather than having them interleaved. That experiment showed no noticeable differences in interference between categories for normal weight versus overweight individuals, though if anything, normal weight individuals showed higher levels of interference. We note that what may have been critical to the findings of Experiment 1 is that there was a contrast and separation between food and non-food categories in order for food to be salient and distracting for overweight individuals.

group. That is, perhaps there would be one category in which overweight/obese individuals were susceptible to distraction regardless of semantic content. We therefore conducted Experiment 2 to examine what would happen in the complete absence of food-related information in the recent-probes task.

Experiment 2

The results of Experiment 1 were consistent with the hypothesis that overweight/obese individuals have increased difficulty removing irrelevant information from working memory—a form of task-intrinsic distraction—compared with their lean counterparts. However, this appears to be the case only where food-related information is concerned. Additionally, the results are consistent with the hypothesis that dieting individuals, who must spend cognitive resources keeping their diet plans on track and thinking about food, are also susceptible to increased task-intrinsic distraction, from food-related information only.

However, it could be argued that with any two categories of stimuli, a general impairment in the ability to efficiently manage the contents of working memory could manifest as an imbalanced response to proactive or semantic interference in one category only. Further, the country category in Experiment 1 was presented in the context of a task that contained food information. What would the pattern of performance look like if there were no food-related stimuli whatsoever? We hypothesized that in the absence of food-related information, overweight/obese, and dieting individuals would not show any evidence of impaired performance relative to lean or non-dieting controls. Specifically, we hypothesized that there would be no evidence of increased semantic or proactive interference in obese or dieting individuals when food-related stimuli were not present. This specific hypothesis follows from our broader interest in the concept that there must be food-specific cognitive markers of dysregulated thought or behaviour about food in individuals who carry excess weight. However, this directly contradicts the hypothesis that might follow from previous studies on obesity and cognition in which generalized cognitive impairments or increased responsiveness to external stimuli have been found (e.g., Herman et al., 1978; Rodin, 1973; Smith et al., 2011). Experiment 2 was designed to adjudicate between these two possible outcomes.

Method

Participants. Fifty-three adults between the ages of 18 and 30 were recruited to the study and were compensated for their time. Two participants were excluded for a previous head injury with loss of consciousness, and one participant was excluded for the use of a prescription migraine medication. These participants were replaced to yield a final sample of 50, with 25 participants in each weight group. All included subjects were healthy with no reported medical diagnosis or medication that would influence their weight. One obese participant with a BMI > 45 also reported a diagnosis of Type 2 diabetes. See Tables 2.1 and 2.2 for participant characteristics.

Materials. Words used in the task were 25 flower names (4-8 letters in length; mean length = 6.08, median = 6) and 25 country names (4-7 letters in length; mean length = 5.72, median = 6).

Task. Task Parameters were identical to those in Experiment 1, except that flower names were used instead of food names.

Procedure. Procedure was identical to that of Experiment 1. The inter-rater reliability of visual adiposity ratings was .79 in this sample.

Results

Overall Performance

Analyses on RT and accuracy data indicated that the overweight/obese group was slower and less accurate overall, regardless of stimulus category. See Tables 2.5 and 2.6 for overall accuracy and RT data. An ANOVA on accuracy data yielded significant main effects of group, $F(1, 48) = 5.22$, $p < .03$, $\eta_p^2 = .098$, and trial type, $F(3, 144) = 13.26$, $p < .0001$, $\eta_p^2 = .216$. The main effect of trial type was due to significant accuracy differences between all trial types except recent negatives and non-recent negative mismatch probes ($t(49) = 1.59$, $p > .10$), with mismatch non-recent negative responses being the most accurate, followed by recent negatives, matching non-recent negatives, and positives, all $t(49)$ 2.2, all $p < .03$. The main effect of group was largely due to marginal differences in accuracy on flower positive probes, $t(48) = 1.81$, $p < .08$, $d = .519$, and place recent negatives, $t(48) = 1.77$, $p < .09$, $d = .527$, as all other comparisons did not reach significance, all $p > .10$, but were consistent in showing numerically lower accuracy in the overweight/obese group. A t-test on overall accuracy was significant, $t(48) = 2.07$, $p < .05$, $d = .597$, as was a t-test on overall flower accuracy, $t(48) = 2.24$, $p = .03$, $d = .638$. The t-test on overall place accuracy failed to reach significance, but was numerically consistent, $t(48) = 1.42$, $p = .16$, $d = .404$. There were no other significant main effects or interactions, all $F < 1.7$, all $p > .18$

An ANOVA on mean RTs revealed a main effect of group, $F(1, 48) = 8.14$, $p < .007$, $\eta_p^2 = .145$. Planned comparisons revealed that the main effect of group was driven by significant differences in RT on all probe types, regardless of stimulus type, all $t(48) > 2.3$, all $p < .03$. A t-test on overall RT was also significant, $t(48) = -2.85$, $p < .007$, $d = -.810$. This significant difference was present for both overall flower RT, $t(48) = -2.63$, $p = .01$, $d = -.745$, and overall place RT, $t(48) = -2.99$, $p = .004$, $d = -.853$. There was also a main effect of trial type, $F(3, 144) = 39.32$, $p < .0001$, $\eta_p^2 = .450$. The main effect of trial type resulted from significant differences between all trial types except recent negatives and positive probes, ($t(49) = .08$, $p > .9$), with mismatch non-recent negative responses being the fastest, followed by recent negatives, positives, and matching non-recent negatives, all $t(49) > 4.2$, all $p < .0001$. There were no other significant main effects or interactions, all $F < 1.4$, all $p > .2$.

As before, we examined the influence of dieting on task performance. We again divided participants into dieter and non-dieter groups using the procedure outlined in Experiment 1, yielding a sample of 16 dieters and 34 non-dieters. The analyses using dieting status did not reveal any consistent pattern of worse performance for current dieters. An analysis of accuracy data showed a main effect of trial type, $F(3, 144) = 16.19$, $p < .0001$, $\eta_p^2 = .252$, and a significant trial type by dieting status interaction, $F(3, 144) = 3.53$, $p < .02$, $\eta_p^2 = .069$. There was a significant three way interaction between stimulus type, trial type, and dieting status, $F(3, 144) = 3.75$, $p < .02$, $\eta_p^2 =.072$. Planned comparisons revealed that the significant interactions were driven by two significant differences in which dieters performed differently than non-dieters: in place non-recent negative matching category trials, $t(48) = 2.02$, $p < .05$, $d = .635$, in which dieters outperformed non-dieters, and place positive probe accuracy, $t(48) = -2.66$, $p = .01$, $d = -.807$, in which dieters performed worse than non-dieters. There were no other significant main effects or interactions, *F*s < 1, *p*s > .75

In an ANOVA incorporating stimulus type, trial type, and dieting status on mean RTs, there was a main effect of trial type, $F(3, 144) = 34.26$, $p < .0001$, $\eta_p^2 = .416$. Planned comparisons revealed no significant group differences between any trial type within either stimulus category, all $p > .2$. There were no other significant main effects or interactions, all $F < 1.9$, all $p > .10$

Semantic Interference

Semantic interference results were consistent with our hypothesis that overweight and normal weight, and dieting and non-dieting participants would not show differential susceptibility to food-neutral interference. Analysis of semantic interference scores considering BMI yielded no main effects of group or stimulus and no interaction, all $F < 2.2$, all $p = .15$. Planned comparisons showed that neither flower nor place interference scores, were significantly different between groups, both $p > .2$, nor within subjects, both $p > .9$.[7] Analysis of semantic interference scores considering dieting status showed no main effects or interactions and no significant differences between place or flower scores, all $p > .2$, nor any within subjects differences, both $p > .13$.[8] See Figures 2.4 and 2.5 for interference score data.

Proactive Interference

Proactive interference results were also consistent with our hypothesis that participants would not show differential susceptibility to food-neutral interference. Analysis of proactive interference scores considering BMI yielded a similar pattern, with no main effects or interaction and no significant planned comparisons, all $p > .17$. When considering dieting status, there were no significant main effects or interactions and no significant differences in either place or flower scores, all $p > .3$, nor any significant within subjects differences, both $p > .5$.[9]

Correlation Analyses

Overall, there was not a consistent pattern of correlations between eating behaviour metrics and task performance. There were no significant correlations between any flower interference score and any questionnaire variable of interest, all $r < .24$, all $p > .10$. There was

[7] Using combined accuracy and RT z-scores in a similar ANOVA showed no main effects or interactions, all $p > .4$, and no significant within or between subjects comparisons, all $p > .4$.
[8] An ANOVA using combined accuracy and RT z-scores revealed no main effect of dieting status or stimulus type, both $F < 1$, $p > .4$, but a significant dieting status x stimulus type interaction, $F(1, 48) = 4.89$, $p < .04$, $\eta_p^2 = .092$. This was due to dieters having less interference than non-dieters in place semantic interference, $t(48) = -1.97$, $p = .055$, $d = -.619$, but numerically more interference than non-dieters in flower semantic interference, $t(48) = 1.61$, $p = .11$, $d = .490$. Dieters had significantly higher interference for flowers compared to places, $t(15) = 3.33$, $p < .01$, $d = .841$, but non-dieters did not, $p > .2$.
[9] Using combined accuracy and RT z-scores yielded no main effects, interactions, or planned comparisons, all $p > .3$, considering either dieting status or weight group.

one significant correlation between place proactive interference and overweight preoccupation, $r = -.28$, $p < .05$. All other $|r| < .27$, all $p > .07$.

Discussion

Experiment 2 showed that in a completely food-neutral task there were no deleterious effects of overweight/obesity, current dieting, or dietary restraint on cognitive control. This was largely true whether considering the dichotomous between-groups comparisons or the correlational analyses using continuous variables. There was no clear influence of any variable of interest on interference scores, though there was a general slowing of responses in the overweight/obese group. This slowing was non-specific and was not inconsistent with our specific hypothesis about cognitive control, but rather indicates that there may have been some general sluggishness in memory retrieval.[10]

The absence of any other weight-related or dieting-related effects underscores that the decrement in cognitive control documented in Experiment 1 was specific to food-related information. It does not seem to be true that overweight individuals are susceptible to task-intrinsic distraction from any type of information—indicated both by the lack of place-related effects in Experiment 1 and the lack of any consistent effects in Experiment 1—rather it seems to be that the vulnerability to cognitive control disruption is restricted to food information that is task-relevant or task-intrinsic, as in the semantic interference result in Experiment 1.

General Discussion

[10] Though the general slowing documented above might have been interpreted as evidence consistent with general memory impairment, we have not replicated this general sluggishness in other working memory studies (e.g., see Chapter III). Additionally, in a separate experiment using a standard, item-recognition working memory task with four memoranda, we found no evidence of slowed or less accurate responding in overweight participants. Finally, those same participants completed a reaction time task including simple RT, choice RT, and conflict RT conditions. Those data again yielded no evidence of general slowing or decreased accuracy. We therefore suspect that the slowed and less accurate responses here were elicited in the context of interference in a working memory task, but we refrain from interpreting these findings further until they are replicated.

The experiments presented here offer preliminary evidence that although there may be some cognitive marker of overweight/obesity in terms of cognitive control performance, this marker can be specific. In particular, the present experiments offer evidence that overweight/obese individuals show more interference from semantically-related information in a verbal working memory task only when this information is food-related. Additionally, individuals who are currently dieting, and to a lesser extent, individuals who have a long-term pattern of restrained eating behaviour, demonstrate similar effects, with susceptibility to food-related semantic interference in a working memory task. Finally, the degree to which individuals are susceptible to food-related semantic interference in the recent-probes task is related not only to dieting status, but also to worry about being overweight.

Experiment 2 provided evidence consistent with the hypothesis that such exaggerated interference effects are related to the presences of food stimuli, as they were not present in a completely food-neutral task. BMI, dieting, restraint, and overweight preoccupation were unrelated to performance in the recent-probes task involving flower and place names as stimuli, disconfirming any hypothesized generalized interference or cognitive control vulnerability in working memory.

The present results have a number of implications for theories of cognitive contributions to obesity. In particular, Schachter's (1968) theory of externality in obesity suggested that obese individuals should be more disrupted by distraction during task performance, consistent with the current experiments. However, Schachter and colleagues focused largely on irrelevant distraction, and often task-extrinsic distraction. The externality theory was originally posited as one mechanism through which obese individuals came to be heavier—they paid more attention to external stimuli generally, were therefore more reactive to external food stimuli, and therefore exerted less top-down control over their food consumption. This argument has fallen out of favour, in part due to evidence that recurrent patterns of restriction and binging (i.e., restrained eating; Herman & Polivy, 1980; Herman et al., 1978) contribute to weight gain, while evidence that externality and general distractibility are related to weight gain is sparse. The present experiments suggest a different version of increased distractibility in overweight/obesity, in which it is not a general susceptibility to distraction that causes weight gain, but perhaps a specific food-related susceptibility to certain kinds of distraction that mark eating behaviours and attitudes associated with higher BMI.

The present results contradict the idea that overweight/obese individuals are more generally susceptible to task-relevant, task-intrinsic distraction—the results suggest only content-based distraction in the form of semantic interference, not time-based distraction in the form of proactive interference, is potentially problematic. Additionally, no evidence of difficulty resisting distraction from food-neutral semantically-related information emerged. That is, when food information is not included in the task, overweight/obese individuals are not disadvantaged. These results cannot yet be generalized, however, to other types of distraction or other cognitive processes. We only assessed distraction from task-intrinsic, internal representations, and only in a working memory context. Future research can evaluate the impact of task-extrinsic distraction, and distraction during other types of cognitive processing.

The present results are not able to adjudicate between the possibilities that the susceptibility to food-related task-intrinsic distraction contributes to weight gain, or that it develops as a result of being overweight or attempting to lose weight. It is possible that food-specific distractibility precedes some kind of difficulty with food consumption regulation, body image, or weight-based experiences of prejudice. For example, a predisposition to elevated food-related motivation or reward response could cause difficulty with regulation of food consumption, and result in heightened cognitive responses to food, manifesting as heightened distractibility. Alternatively, given the association between food-related semantic interference scores and variables like overweight preoccupation and dieting status, interference vulnerability could emerge as a result of thinking about food consumption, weight regulation, or dieting—that is, worrying about being or becoming overweight and how to prevent or reverse it. One hypothesis might be that individuals who have difficulty preventing food-related information not included in the current memory set from interfering with working memory task performance would have more difficulty regulating food-related thoughts in non-laboratory contexts as well. This could potentially interfere with healthy weight and eating regulation efforts, contributing to difficulty maintaining healthy eating habits or a healthy weight. This is consistent with a study by Shaw and Tiggemann (2004) showing that preoccupation with weight, food, and shape mediated an effect of dieting on working memory, where dieters were shown to have smaller working memory capacity. Additionally, a study by Higgs, Robinson, and Lee (2012) showed that when individuals are tasked with keeping a food representation in working memory, they show a subsequent attentional bias to food images.[11] Though this study was not conducted with overweight or obese individuals, in combination with our results showing increased difficulty removing information from working memory, it seems that overweight and obese individuals would be even more susceptible to attentional biasing caused by working memory contents. Alternatively, individuals who have increased responsiveness to food might engage in cognitive restraint with food-related information in an effort to regulate their responses. This real-world

[11] One might hypothesize that hunger could influence these factors. We collected ratings on a scale from one to ten at the end of the experiment of current hunger and retrospective reports of hunger at the beginning of the experiment. These measures were not associated with any interference scores in Experiment 1 or 2 (all $|r| < .26$, all $p > .07$).

difficulty with food and efforts at restraint might then manifest in cognitive tasks as well. This explanation is also compatible with the Higgs et al. (2012) result and the Shaw and Tiggemann (2004) result, but with the causal direction reversed.

One alternative hypothesis is that instead of difficulties with control processes in working memory, the semantic interference results arose as a result of differences in the organization of semantic information in long-term memory. In particular, the semantic category of food items could have fuzzier boundaries in overweight participants. If foods are represented less distinctively, it could be harder to discern among individual items within the category. This hypothesis would be most directly assessed by examining semantic distance within each category. However, we do not have data available for the current stimuli or participants to address this possibility. We do have peripherally relevant data in the form of familiarity ratings for food, country, flower, and non-food words in two separate samples of overweight and normal weight participants. To support the semantic hypothesis outlined above, one would expect higher familiarity ratings among the overweight group. Instead, in a sample of 13 normal weight and 6 overweight participants, normal weight participants had numerically higher familiarity ratings for food, flower, and country stimuli, though none of these comparisons were statistically significant, all $p > .10$. In another sample of 52 normal weight and 19 overweight participants, normal weight participants had higher familiarity ratings of healthy, unhealthy, and non-food words, though again none of these comparisons were significant, all $p > .07$. To directly test the semantic organization hypothesis, a future study can gather data to evaluate semantic distance in a sample of participants completing the recent probes task, but the data currently available are not consistent with such an explanation. We thus consider the control hypothesis further in this chapter and Chapter III.

The present studies suggest that these mechanisms may be at play in some way in the real world, since they are related to self-reported behaviour and thought patterns, as well as BMI, which can be considered a proxy for eating behaviour. However, the current data were obtained in a context in which participants were not faced with images or videos of food, there were no food odors, and no opportunities to actually consume or acquire any of the foods referenced by the stimuli. This is particularly interesting, because even at the level of abstraction achieved by using verbal food labels, there is some evidence of difficulty removing or preventing food information from access to working memory among the overweight and dieting. Previous research has shown substantial differences in decision making behaviour and neural responses to real objects compared with images or labels (e.g., Snow et al., 2011), so future research may focus on developing some means to test the hypotheses advanced here using more realistic food stimuli.

In addition, the recent-probes task assesses the ability to regulate the contents of working memory implicitly. That is, participants were not instructed to *try* to remove any information from mind, nor to prevent any information from capturing attention. This leaves open the possibility that an explicit instruction to ignore or remove food-related information from working memory could resolve the interference control difficulties evinced by our overweight/obese sample from Experiment 1. Future research can examine which manner of downregulating food-related information is disrupted in obese individuals in working memory: the access of irrelevant information to working memory, or the deletion of irrelevant information from working memory (i.e., Hasher, Zacks, & May, 1999; Lustig, Hasher, & Zacks, 2007). Additionally, there was also no task-irrelevant or task-extrinsic distraction presented, leaving us unable to evaluate the possibility that overweight/obese individuals are more susceptible to task-extrinsic distraction either generally or specifically in a working memory context.

The present data also have implications for cognitive control theories. We have documented a stimulus-specific decrement in the ability to control interference. Note that this is not a failure to control semantic interference generally, but a failure to do so only for one specific semantic category. Previous studies have documented specificity in cognitive control deficits related to the valence of a stimulus (e.g., Berman et al., 2011; Joorman et al., 2010), and memory performance differences due to content-related expertise (e.g., Chase & Simon, 1973; Gobet & Simon, 1998; Ricks et al., 2007), however, our data are a novel demonstration that the control of working memory performance can be affected negatively by the semantic content of the task. This is further evidence that cognitive control abilities are malleable and context-dependent.

It is also possible that the present results reflect a motivational issue. Participants were offered performance incentives for quick and accurate responding—their final scores were converted to cash bonuses, and they were informed of this at the beginning of the task. Perhaps normal weight participants were more motivated by this incentive, found the task more intrinsically motivating, or were better able to harness their motivation into both quick and accurate responses. This could have been reflected in bonus scores, but although overweight/obese individuals had, on average, lower total bonus scores, (M = 201.84 vs. 168.80 for normal vs. overweight, respectively) this result was not reliable ($p > .20$). Overweight/obese participants may have also found the food-related content provocative of worry about their size or being evaluated on their weight. Though they were not informed of the specific purpose of the study in advance, participants knew that the study was investigating food and cognition, and could have found this to be threatening. Previous research has established that overweight individuals experience prejudice and stigma (see McHugh & Kasardo, 2012; Puhl & Brownell, 2001 for reviews), so perhaps the explicit inclusion of food content evoked a stereotype threat-like reaction. Future studies can investigate these possibilities.

Though the mechanism by which food-related information comes to be disruptive to overweight/obese or dieting individuals cannot be determined from the present data, the results suggest the hypothesis that there is some food-specific cognitive marker associated with obesity. Additionally, the results raise the possibility that if vulnerability to task-intrinsic distraction from food information can be ameliorated, there could be real-world consequences in terms of the ability to effectively regulate food-related thought outside the lab. Thus, the present experiments provide a step toward understanding the cognitive mechanisms at play in obesity, which is a necessary precursor to the development of cognitive tools to augment existing programs to prevent, or reverse weight gain.

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Table 2.1 Participant characteristics by weight group

	Experiment 1		Experiment 2	
	NW	OW	NW	OW
N	25	25	25	25
Age	19.8 (1.5)	20.1 (1.6)	19.8 (2.1)	19.5 (2.1)
Sex	68.00%	56.00%	68.00%	68.00%
Years of Education	14.1 (1.7)	14.0 (1.5)	14.0 (1.7)	13.6 (1.7)
BMI	22.2 (1.9)	29.0 (5.3)***	21.2 (2.1)	30.3 (3.8) ***
Average Adiposity Ratings	1.9 (0.5)	3.0 (0.9) ***	1.6 (0.5)	3.0 (0.5) ***
DEBQ Restraint	2.57 (0.15)	3.06 (0.18)*	2.57 (0.18)	2.84 (0.15)
DEBQ External Eating	3.42 (0.12)	3.20 (0.12)	3.43 (0.09)	3.26 (0.11)
DEBQ Emotional Eating	2.65 (0.16)	2.63 (0.14)	2.53 (0.15)	2.66 (0.20)
TFEQ Uncontrolled Eating	2.27 (0.10)	2.17 (0.10)	2.31 (0.12)	2.32 (0.12)
TFEQ Cognitive Restraint	2.67 (0.14)	2.96 (0.12)	2.51 (0.16)	2.83 (0.13)
TFEQ Emotional Eating	2.17 (0.17)	2.25 (0.15)	2.04 (0.14)	2.24 (0.17)
Overweight Preoccupation	2.38 (0.15)	2.72 (0.22)	1.97 (0.17)	2.74 (0.16) **
Current Dieting Status	1.56 (0.17)	2.45 (0.30)**	1.40 (0.17)	2.52 (0.29) **
Restraint Scale Total	13.63 (1.19)	18.13 (1.20) **	11.17 (1.10)	18.08 (0.72) ***

Note. Age, Years of Education, BMI, and Adiposity Ratings are *M* (*SD*). All other measures are *M* (*SE*), except Sex, which is % female. *** = $p < .0001$, ** = $p < .01$, * = $p < .05$., † = p < .10.

Table 2.2 Participant characteristics by diet status

	Experiment 1		Experiment 2	
	Dieter	Non-Dieter	Dieter	Non-Dieter
N	15	35	16	34
Age	20.1 (2.4)	19.4 (1.9)	19.9 (1.3)	20.0 (1.7)
Sex	86.67%	60.00%	68.75%	58.82%
Years of Education	14.1 (1.6)	13.2 (1.5)	14.0 (1.7)	14.0 (1.6)
BMI	27.4 (5.7)	25.0 (5.6)	28.4 (6.3)**	24.3 (4.2)
Average Adiposity Ratings	2.6 (0.8)	2.2 (0.9)	3.0 (1.1)**	2.2 (0.6)
DEBQ Restraint	3.38 (0.16)***	2.41 (0.12)	3.54 (0.17)***	2.47 (0.12)
DEBQ External Eating	3.17 (0.12)	3.42 (0.09)	3.25 (0.11)	3.34 (0.11)
DEBQ Emotional Eating	2.65 (0.23)	2.57 (0.15)	2.78 (0.17)	2.57 (0.13)
TFEQ Uncontrolled Eating	2.27 (0.18)	2.33 (0.09)	2.35 (0.11)	2.16 (0.08)
TFEQ Cognitive Restraint	3.21 (0.14)**	2.43 (0.12)	3.38 (0.13)***	2.55 (0.10)
TFEQ Emotional Eating	2.16 (0.21)	2.14 (0.13)	2.17 (0.21)	2.24 (0.13)
Overweight Preoccupation	3.37 (0.16)***	1.92 (0.10)	3.52 (0.18)***	2.10 (0.11
Current Dieting Status	3.80 (0.17)***	1.17 (0.06)	3.69 (0.20)***	1.24 (0.07)
Restraint Scale Total	18.71 (0.62)**	12.94 (1.00)	21.81 (1.11)***	12.91 (0.83)

Note. Age, Years of Education, BMI, and Adiposity Ratings are *M* (*SD*). All other measures are *M* (*SE*), except Sex, which is % female. *** = $p < .0001$, ** = $p < .01$, * = $p < .05$., † = p < .10.

Table 2.3 RT and accuracy data from Experiment 1 by weight group

	Normal Weight		Overweight	
	Accuracy (%)	RT (ms)	Accuracy (%)	RT (ms)
Food Positive Probes	96.84 (0.67)	628.29 (19.94)	95.56 (0.88)	651.15 (17.42)
Food Non-Recent Negative Match Probes	95.68 (1.46)	656.77 (17.29)	96.04 (2.10)	713.58 (23.50)
Food Non-Recent Negative Mismatch Probes	98.04 (0.87)	605.81 (15.61)	98.36 (0.83)	618.85 (14.75)
Food Recent Negative Probes	97.40 (1.32)	616.35 (16.11)	98.36 (0.90)	643.20 (16.67)
Place Positive Probes	96.04 (0.83)	627.31 (20.05)	96.00 (1.16)	664.96 (19.66)
Place Non-Recent Negative Match Probes	97.08 (0.93)	679.59 (21.85)	95.40 (1.59)	696.22 (19.13)
Place Non-Recent Negative Mismatch Probes	99.36 (0.44)	600.83 (19.37)	98.72 (0.60)	626.10 (16.53)
Place Recent Negative Probes	98.52 (0.53)	630.80 (19.55)	97.88 (0.86)	643.68 (17.00)

Note. All measures are *M* (*SE*).

Table 2.4 RT and accuracy data from Experiment 1 by dieting status

	Dieter		Non-Dieter	
	Accuracy (%)	RT (ms)	Accuracy (%)	RT (ms)
Food Positive Probes	95.40 (1.47)	653.42 (26.87)	96.54 (0.49)	633.85 (15.10)
Food Non-Recent Negative Match Probes	91.73 (3.36)	726.39 (35.85)	97.63 (1.00)	667.51 (14.34)
Food Non-Recent Negative Mismatch Probes	98.33 (1.22)	613.65 (17.17)	98.14 (0.68)	611.77 (13.50)
Food Recent Negative Probes	97.80 (1.46)	628.84 (19.79)	97.91 (0.96)	630.17 (14.47)
Place Positive Probes	94.33 (2.10)	666.36 (27.26)	96.74 (0.45)	637.47 (16.55)
Place Non-Recent Negative Match Probes	95.67 (2.25)	697.57 (26.46)	96.49 (0.92)	683.76 (17.40)
Place Non-Recent Negative Mismatch Probes	98.40 (0.86)	616.56 (20.71)	99.31 (0.38)	612.14 (16.05)
Place Recent Negative Probes	97.00 (1.31)	642.00 (20.23)	98.71 (0.44)	635.20 (16.36)

Note. All measures are *M* (*SE*).

Table 2.5 RT and accuracy data from Experiment 2 by weight group

	Normal Weight		Overweight	
Probe Type	Accuracy (%)	RT (ms)	Accuracy (%)	RT (ms)
Flower Positive Probes	96.12 (0.70)	607.31 (16.70)	93.92 (1.00)	664.03 (18.47)
Flower Non-Recent Negative Match Probes	98.08 (0.70)	627.23 (18.71)	97.08 (0.93)	698.57 (21.82)
Flower Non-Recent Negative Mismatch Probes	99.36 (0.44)	567.41 (13.28)	97.72 (0.89)	616.82 (16.42)
Flower Recent Negative Probes	98.24 (0.47)	599.02 (13.15)	97.60 (0.73)	661.79 (17.22)
Place Positive Probes	96.36 (0.79)	585.21 (15.62)	95.56 (0.88)	661.83 (20.04)
Place Non-Recent Negative Match Probes	96.68 (1.19)	622.95 (16.06)	95.76 (1.08)	696.73 (26.94)
Place Non-Recent Negative Mismatch Probes	99.36 (0.44)	563.59 (12.87)	97.68 (1.03)	614.36 (16.16)
Place Recent Negative Probes	98.88 (0.37)	598.48 (13.63)	97.44 (0.73)	657.13 (17.05)

Note. All measures are *M* (*SE*).

Table 2.6 RT and accuracy data from Experiment 2 by dieting status

	Dieter		Non-Dieter	
Probe Type	Accuracy (%)	RT (ms)	Accuracy (%)	RT (ms)
Flower Positive Probes	94.31 (1.21)	648.52 (24.37)	95.35 (0.72)	629.63 (15.40)
Flower Non-Recent Negative Match Probes	96.94 (1.28)	665.90 (27.46)	97.88 (0.61)	661.49 (18.36)
Flower Non-Recent Negative Mismatch Probes	99.50 (0.50)	588.39 (20.99)	98.09 (0.70)	593.86 (13.08)
Flower Recent Negative Probes	98.50 (0.62)	628.11 (19.46)	97.65 (0.56)	631.49 (14.62)
Place Positive Probes	93.81 (1.06)	649.01 (24.74)	96.97 (0.65)	611.53 (16.32)
Place Non-Recent Negative Match Probes	98.50 (0.81)	652.64 (21.11)	95.15 (1.07)	663.23 (22.14)
Place Non-Recent Negative Mismatch Probes	98.44 (1.14)	597.13 (17.93)	98.56 (0.65)	585.14 (13.67)
Place Recent Negative Probes	97.75 (0.81)	643.09 (19.55)	98.35 (0.48)	620.61 (14.37)

Note. All measures are *M* (*SE*).

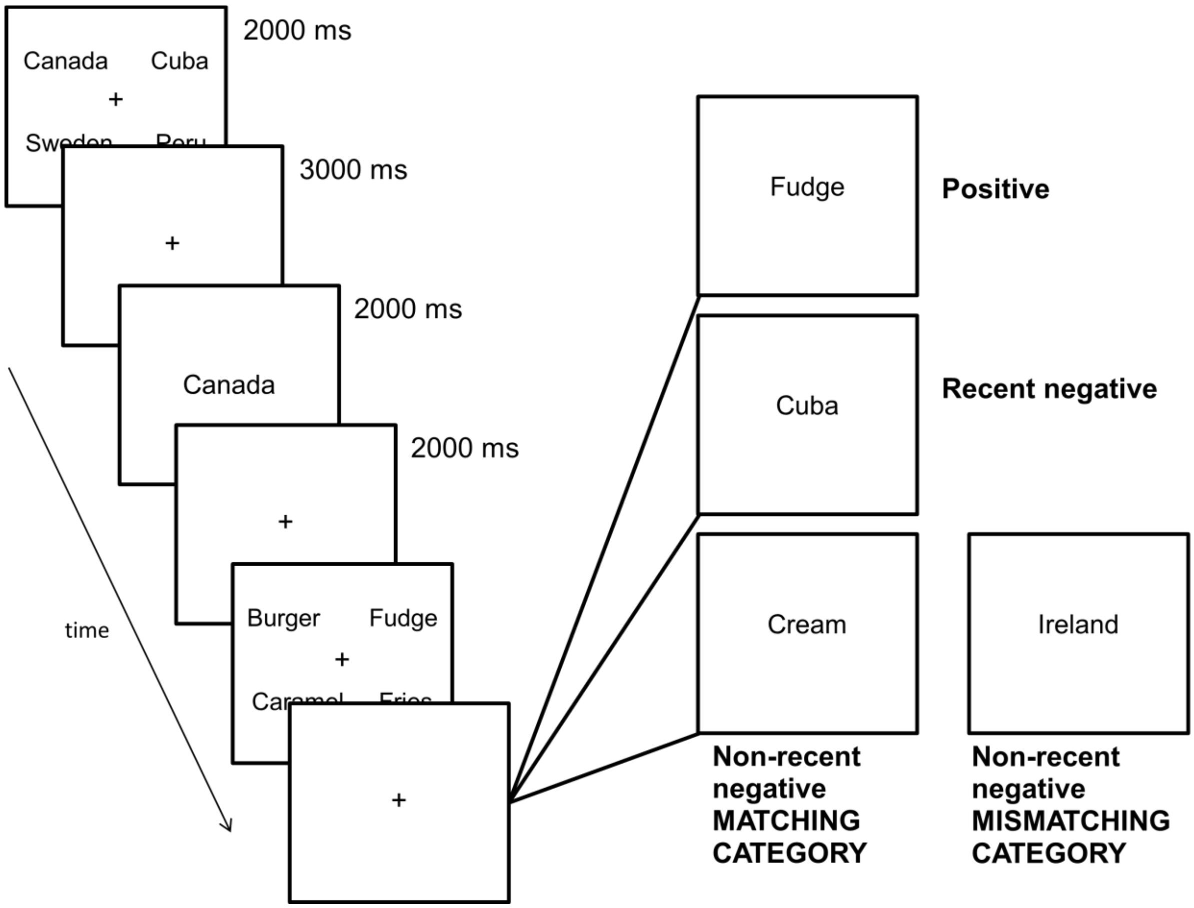

Figure 2.1 Recent probes trial diagram.

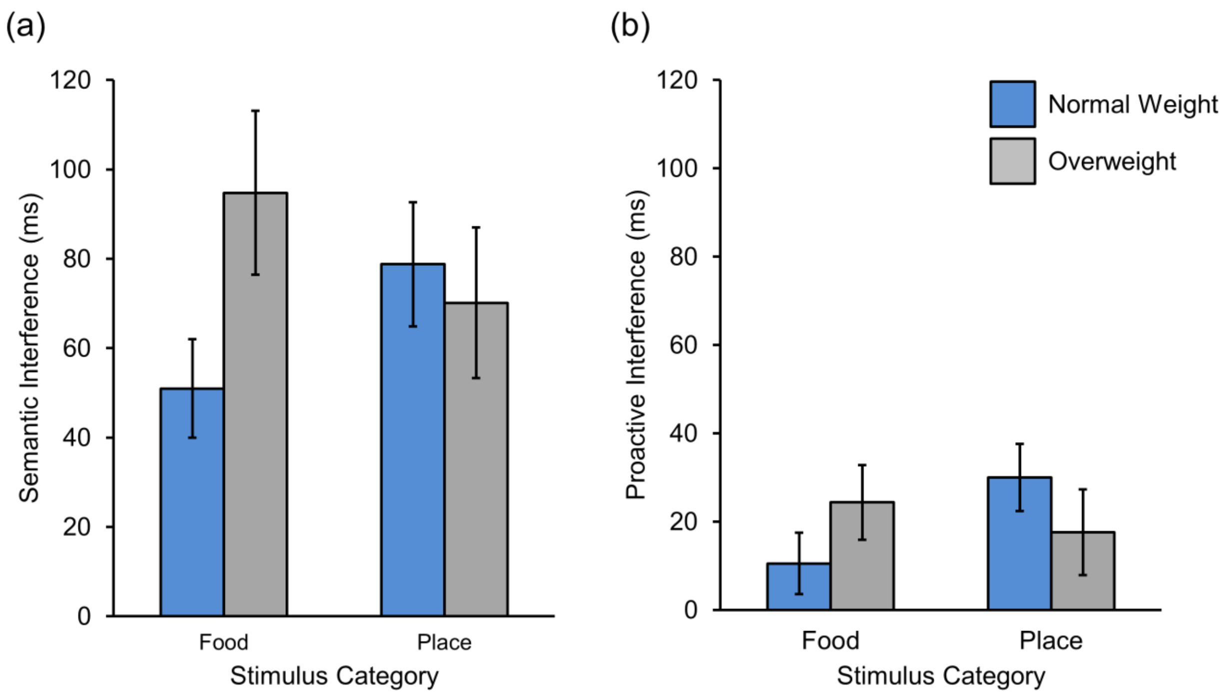

Figure 2.2 Experiment 1 interference scores by weight group: (a) semantic interference and (b) proactive interference.

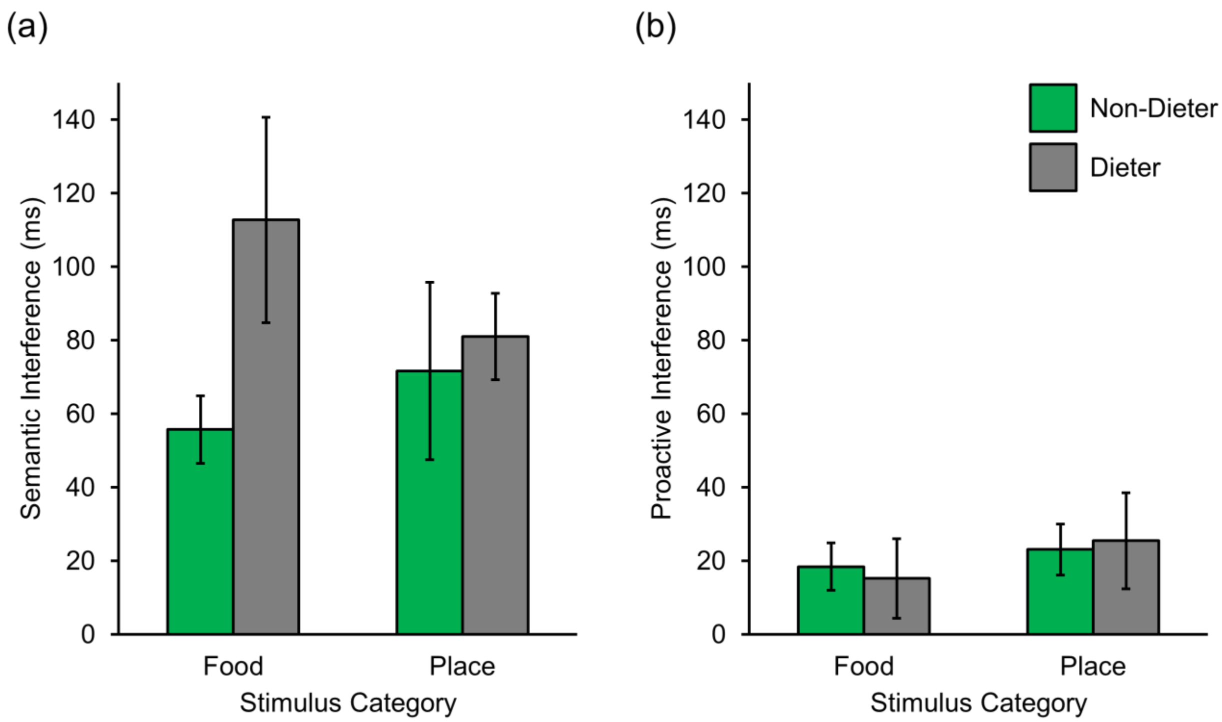

Figure 2.3 Experiment 1 interference scores by dieting group: (a) semantic interference and (b) proactive interference.

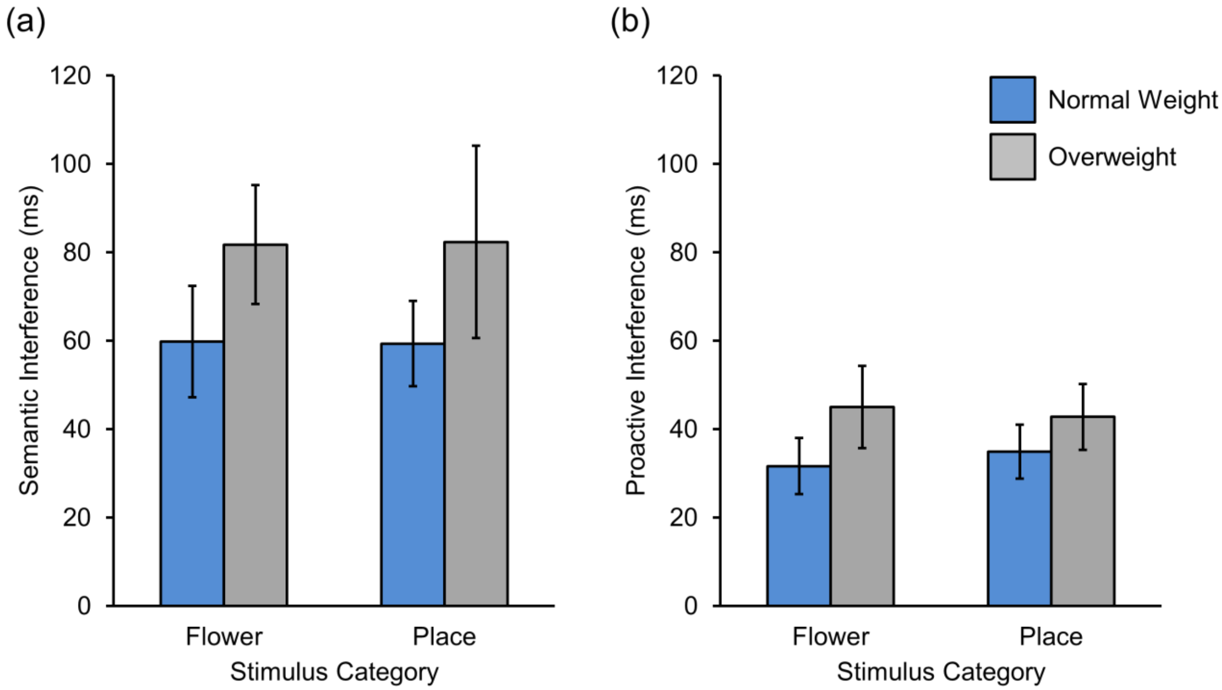

Figure 2.4 Experiment 2 interference scores by weight group: (a) semantic interference and (b) proactive interference.

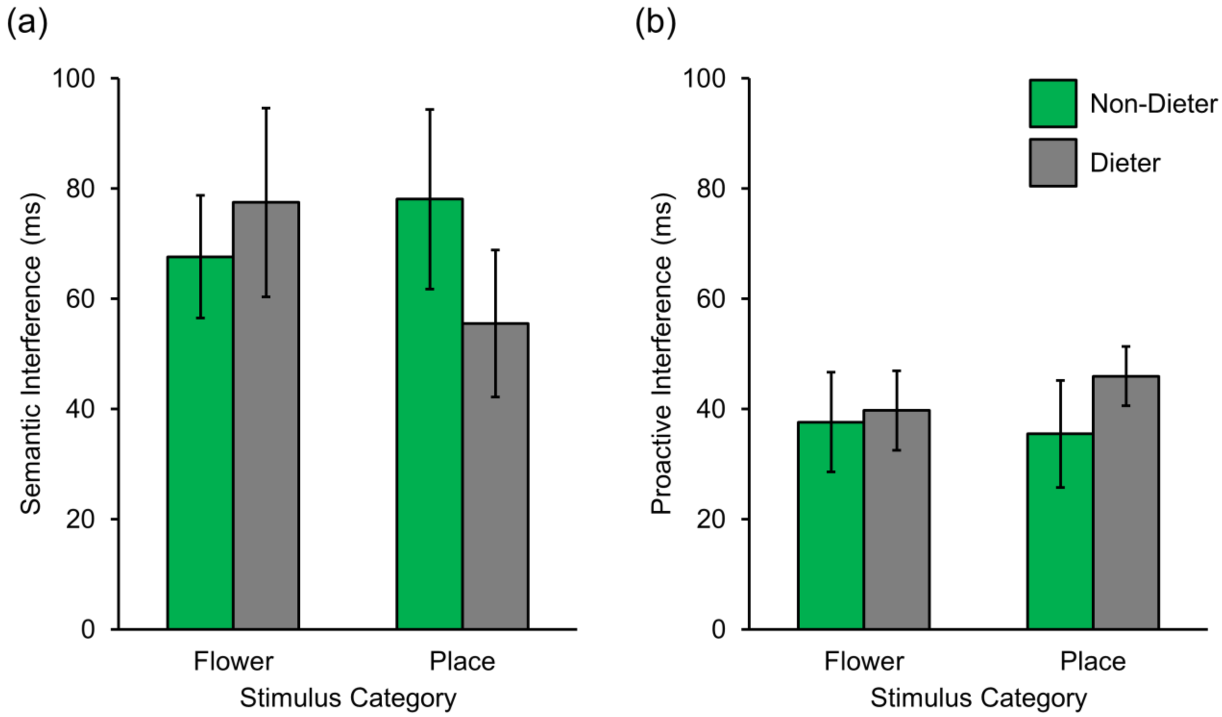

Figure 2.5 Experiment 2 interference scores by dieting group: (a) semantic interference and (b) proactive interference.

CHAPTER III

Explicit Task-Intrinsic Distraction in Working Memory

Introduction

The cognitive contributions and consequences of obesity are not yet well understood. Previous investigations have documented generalized impairments in executive function across a variety of tasks, however, our own previous experiments examining executive function in working memory using the recent-probes task suggest instead that, at least in the working memory domain, there are specific rather than general impairments in performance related to obesity. We did not find evidence of overall impairment, nor did we find evidence that impairment in resistance to task-intrinsic distraction was equally severe across all stimuli. Instead, we found a specific deficit in the ability to control interference from food-related information encountered in the normal course of task performance.

Our previous study of working memory and susceptibility to task-intrinsic distraction leaves several questions unanswered. In particular, one of the characteristics of the recent-probes task is that the control of interference required for good performance occurs during the normal course of the task, and the interference manipulations are opaque to subjects (e.g., Bunge, Ochsner, Desmond, & Glover, 2001). That is, participants are not instructed that interference will occur, nor are they explicitly instructed to manage it. Thus, it remains possible that if participants were instructed to *intentionally* block or delete food-related information from working memory in a task encouraging volitional control over working memory contents, the food-related vulnerability we documented in obese and dieting individuals would no longer be present.

Specifically, if the source of the impairment is in the self-initiated control required to perform the recent-probes task, but directed, explicit control supported by task instructions is unaffected, there should be no adverse effects on performance in overweight/obese participants. We explore this hypothesis in the experiment reported here.

The distinction between allowing information to access working memory and deleting it from working memory has been studied quite extensively in cognitive psychology. Hasher and colleagues (i.e., Hasher, Zacks, & May, 1999; Lustig, Hasher, & Zacks, 2007) have argued that the functions of access and deletion are component functions of inhibition. Other researchers have referred to these functions together as interference resolution or inhibition (e.g., Miyake et al., 2000; Smith & Jonides, 1999), or drawn the distinction between distractor resistance (preventing access) and intrusion resistance (deletion) in parsing the executive components of working memory function (e.g., Friedman & Miyake, 2004; Nee & Jonides, 2008; Nee et al., 2013). Recently, neuroimaging studies have suggested that though there are shared neural substrates, the two functions are also neurally separable (see Nee et al., 2013 for a review). For our purposes, it is important to note that vulnerability to food information causing interference in working memory as demonstrated in our recent probes study could occur as a result of impairment in either or both of the above functions, which we will refer to as access and deletion for the remainder of this chapter. Consider, for example a case where food information in the environment is allowed to enter the focus of attention when it is not relevant to the task at hand. As the focus of attention (and region of direct access; see Oberauer, 2002) is capacity limited, the presence of irrelevant food information would prevent the full capacity of working memory from being allocated to the task at hand, potentially disrupting performance. Preventing access when food information is irrelevant is therefore important. Additionally, if once-relevant food information is not efficiently removed from the focus of attention (or region of direct access), it could again prevent the entry and maintenance of relevant information, thus disrupting performance. Deletion is therefore also paramount to efficient working memory function.

We propose to use two tasks to examine the access and deletion functions as they relate to food-related interference in working memory, to gain fuller understanding of our previous results using the recent-probes task. The first is an item recognition working memory task in which participants are instructed to ignore half of the memory set before encoding (the ignore task; Nee & Jonides, 2008; Nee & Jonides, 2009). Probe items can then be selected to match the attended half of the stimuli or the ignored half of the stimuli, inducing a negative priming-like effect (e.g., Tipper, 1985), or they can be non-matching. This allows the assessment of interference from ignored items, and by introducing a semantic category manipulation like the one we previously employed in the recent-probes task, it allows the assessment of interference from food versus non-food items. This task will allow the evaluation of the hypothesis that preventing *access* of irrelevant, food-related information to working memory may be disrupted in obese or dieting individuals.

The second is an item recognition working memory task in which participants are instructed to forget half of the memory set after encoding (the forget task; Berman et al., 2011; Nee & Jonides, 2008; Nee & Jonides, 2009; Oberauer, 2001; Zhang, Leung, & Johnson, 2003). Probe items can then be selected to match the attended half of the stimuli, the forgotten half of the stimuli, or a non-matching probe. Unlike the ignore task, subjects must attend to all stimuli before receiving an instruction about which half should be forgotten. Thus, they must allow all stimuli to enter working memory before intentionally removing or focusing on half the stimuli, inducing proactive interference. Note that the forget task as we are conceptualizing it here has its closest relatives in the studies cited above, however, it is also related to the larger body of literature examining directed forgetting in long-term memory (e.g., Basden, Basden, & Gargano, 1993; Bjork, 1972; Kimball & Bjork, 2002; Macleod, 1999; Wylie, Foxe, & Taylor, 2008; Zacks & Hasher, 1994; Zacks, Radvansky, & Hasher, 1996); and the think/no think paradigm (e.g., Anderson, 2003), which have also been used to explore the control of memory process, albeit on a different time scale.

Previous versions of the forget task (but not the ignore task, except in the case of a combined ignore/forget task; Joormann, Nee, Berman, Jonides, & Gotlib, 2010) have employed category manipulations as we do below (e.g., Conway et al., 2000; Festini & Reuter-Lorenz, 2013; Horton & Petruk, 1980; Kimball & Bjork, 2002; Power, Dalgleish, Claudio, Tata, & Kentish, 2000; Steven et al., 2008; Zacks & Hasher, 1996). Our task is most closely related to the emotional category manipulation employed in Berman et al. (2011), wherein two emotional categories of items were displayed on each trial, only two categories of items were used across the whole task, and participants received instructions to forget one of the two categories. In our task, we use the semantic categories we used in our previous recent probes investigation (foods and countries) instead of categories determined by emotional valence, but the task parameters are similar, and the Berman (2011) study provides some rationale for hypothesizing that we will be able to detect a category-specific effect in the forget task. To our knowledge, no other study has previously employed a category manipulation in an ignore task like the one we use here, but based on previous selective attention and attentional bias studies, and the overall similarity in form and structure to the forget task, it is reasonable to hypothesize that we will be able to detect such an effect if one exists using this task.

Administering these two tasks in a single testing session allows a comparison of the ability to exercise volitional control over the contents of working memory by *removing* information from working memory (deletion) and by *preventing* information from accessing the focus of attention in the first place (access). This experimental design allows us to examine whether the documented susceptibility of overweight/obese individuals to task-intrinsic distraction in the working memory domain is due to failure to delete irrelevant information from mind, failure to prevent irrelevant information from accessing working memory, or both.

To our knowledge, this is the first study to examine the volitional control over the contents of working memory using the ignore or forget tasks in obese or dieting individuals. Previous research on obesity and working memory has largely focused on n-back (Gonzales et al., 2010; Stingl et al., 2012; Stingl et al., 2010) or digit span tasks (Boeka & Lokken, 2008; Brooks et al., 2012; Cserjési, Luminet, Poncelet, & Lénárd, 2009; Dailey, 1978; Dore, Elias, Robbins, Budge, & Elias, 2008; Elias, Elias, Sullivan, Wolf, & D'Agostino, 2003; Elias, Elias, Sullivan, Wolf, & D'Agostino, 2005; Gunstad, Lhotsky, Wendell, Ferrucci, & Zonderman, 2010; Gunstad et al., 2008; Kuo et al., 2006; Li, Dai, Jackson, & Zhang, 2008; Lokken et al., 2009; 2010; Waldstein & Katzel, 2005; Walther, Birdsill, Glisky, & Ryan, 2010), and studies have not always found impairment in working memory. Most of these studies have also not included food-related stimuli. This is also the first study to our knowledge to assess attentional bias to food information in the context of a working memory task. Previous research on attentional bias has focused on dot-probe, visual search, and modified Stroop-like tasks (e.g., Braet & Crombez, 2003; Brignell, Griffiths, Bradley, & Mogg, 2009; Castellanos et al., 2009; Davis et al., 2011; Gearhardt, Treat, Hollingworth, & Corbin, 2012; Hou et al., 2011; Loeber et al., 2012; Mobbs et al., 2011; Nathan et al., 2012; Nijs, Muris, Euser, & Franken, 2010; Nijs, Franken, & Muris, 2009; Nummenmaa, Hietanen, Calvo, & Hyönä, 2011; Overduin, Jansen, & Louwerse, 1995;

2012; Smeets, Roefs, & Jansen, 2009; Smith & Rieger, 2006; Tapper, Pothos, & Lawrence, 2010; Yokum, Ng, & Stice, 2011), and again, the effects are not always of similar magnitude, nor are they always present selectively for food stimuli, or selectively in overweight/obese individuals. Many of these studies draw on the addiction literature, which suggests that stimuli to which participants have been sensitized become very effective in attentional capture, as a result of their incentive salience (e.g., Boyer & Dickerson, 2003; Lubman, Peters, Mogg, Bradley, & Deakin, 2000; see also Berridge, 2007; Robinson & Berridge, 2003; see Field & Cox, 2008 for a review of attentional bias in addiction). The same possibility exists for individuals who overconsume food (Berridge, 1996; Gearhardt & Potenza, 2013; Jansen, 1998), and there is evidence that food cue exposure elicits more powerful responses from obese individuals (e.g., Ferriday & Brunstrom, 2010). There is also a specific precedent for impaired directed forgetting in addiction (Zou, Zhang, Huang, & Weng, 2011). Finally, it is important to note that though there are documented attentional bias effects in obese, restrained eaters, and other disordered eaters, as well as in situations of invoked craving, these are not the same condition—not all obese individuals have eating disorders or engage in restrained eating, for example. It is therefore important to consider each of these factors, as well as obesity itself.

Based on our previous results with the recent-probes task, we hypothesized that overweight/obese individuals and currently dieting individuals would have more difficulty suppressing irrelevant food information from working memory in the forget task, even with the explicit instruction to do so (unlike the recent-probes task). Based on the literature demonstrating food-related attentional bias effects using other kinds of attentional control tasks (e.g., dot-probe tasks), we hypothesized that overweight/obese and currently dieting individuals would also have difficulty controlling attention to food information that they were supposed to be disregarding entirely in the ignore task, despite explicit instructions.

Method

Participants. Sixty adults between the ages of 18 and 23 were recruited for the study and were compensated for their time. One participant was excluded for having overall accuracy in the forget task more than 4.5 standard deviations from the overall group mean, a second participant was excluded due to a recent concussion and failure to follow task instructions, a third participant had an uncontrolled medical condition that caused weight gain, and a fourth participant was excluded after computer error resulted in missing data. These participants were replaced to yield a final sample of 56, with 28 participants in each weight group. Weight groups (normal weight, overweight/obese) were defined by BMI cut-offs. BMI is a proxy measure of body fat calculated as a ratio of weight to height in kg/m^2. Groups were defined such that those in the normal weight group had BMI < 25, and those in the overweight/obese group had BMI ≥ 25. All included subjects were healthy with no reported medical diagnosis or medication that would influence their weight. See Table 3.1 for participant characteristics.

Materials. Stimuli were 50 food names (4-9 letters in length; mean length = 5.92, median = 6) and 50 country names (4-9 letters in length; mean length = 5.94, median = 6).

Task. The tasks were programmed in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). As in a typical item-recognition working memory task (Sternberg, 1966), each ignore trial began with an inter-trial interval (ITI) of 750 ms, followed by the ignore instruction (e.g., "IGNORE GREEN") for 1000 ms, then 1000 ms of fixation, followed by the stimulus display of four words that appeared on screen for 3000 ms, followed by a 3000 ms retention interval, and finally a probe item that appeared on screen for up to 1500 ms and disappeared upon response. Each forget trial began with a 750 ms ITI, followed by the stimuli for 3000 ms, then 1000 ms of fixation followed by the forget instruction (e.g., "FORGET BLUE") for 1000 ms, and another 1000 ms of fixation for a total retention interval length of 3000 ms (to match the ignore task), and finally the probe item, which appeared on screen for 1500 ms and disappeared upon response. See Figure 3.1.

In each ignore and forget trial, the stimulus display comprised two food names and two country names. The two words from each category were presented in the same colour font on screen, diagonally opposite each other, to minimize the possibility of subjects only attending to half of the screen (see Figure 3.1). Each category was presented equally often in each font colour in each task, and each category occurred equally often in each spatial location on screen in each task. Colour, position, and instruction were fully crossed within each task such that each feature occurred equally often with each other feature, in both the ignore and forget tasks. Probe items were also drawn equally often from each of the four word locations on screen within each task. Trial order was randomized for each participant. At the beginning of the first task, all 50 food names and 50 country names were randomized, and the first 25 in each list were used for the first task the subject completed, and the second 25 were used for the second task the subject completed, so there was no stimulus overlap between the ignore and forget tasks for any subject. Stimuli were then randomly drawn for each trial.

Each of the ignore and forget tasks contained 128 trials, with 50% of the trials being positive probes (items that were to-be-remembered). Of the other 50%, half were lure probes, in which the probe word was one of the words the participant was instructed to ignore or forget, depending on the task. The remaining 25% of probes were negative probes, in which a probe item was presented that had not appeared in the current memory set, nor had it appeared in any of the previous three trials. That is, each task had 64 positive probes, 32 negative probes, and 32 lure probes, with half of each probe type being attributed to each category. Note that because of the category manipulation, positive probes were always a category match to the current to-be-remembered semantic category, while negative and lure probes were always a category match to the current to-be-forgotten or to-be-ignored semantic category. The critical difference between negative probes and lures was whether or not they were presented with an instruction to ignore or forget them, versus not being presented at all.

Before each task, subjects completed a brief practice block of eight trials containing no words from either of the test categories to familiarize them with the procedure. Participants were also given the option to repeat the practice if they were confused about the task instructions. The practice for the ignore and forget tasks occurred immediately prior to beginning the respective tasks. The two tasks were administered in a counterbalanced order across subjects, and were separated by a one-minute rest period, during which subjects received performance feedback on their speed and accuracy during the previous run. So, for example, a participant could complete the ignore practice, ignore task, forget practice, and forget task. Alternatively, participants could complete the forget practice and task followed by the ignore practice and task. Subjects were instructed to respond quickly and accurately, and they were told that they would receive a score at the end of the experiment based on speed and accuracy that would be converted to a cash bonus to underscore the importance of quick and accurate responding. Participants were not instructed about the category manipulation, the lure manipulation, or any other task parameters before the task began.

One interference score was calculated using mean response times (RTs) for the probe types described above. Mean RT_{LURE} – Mean $RT_{NEGATIVE}$ yielded an index of how much people were slowed by the probe item being an item that they had been instructed to ignore or forget.

Note that this interference score controls for semantic interference, because negative probes were of the same category as the to-be-ignored/to-be-forgotten items. These scores were computed separately for each stimulus type. All mean RTs were trimmed to exclude any response less than 200 ms. It was hypothesized that overweight/obese individuals would have increased interference scores calculated using the food trial RTs compared with the country trial RTs.

Procedure. After completing informed consent and a demographics survey, participants completed the ignore and forget tasks in a counterbalanced order (e.g., half the subjects did ignore, then forget, and the other half did forget, then ignore). Following task completion, they filled out a battery of questionnaires, including the Dutch Eating Behaviour Questionnaire (DEBQ; van Strien, Frijters, Bergers, & Defares, 1986), the Restraint Scale (Herman & Polivy, 1975; 1980), and the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) as assessments of eating behaviours and attitudes; personal and family weight history questions to assess individual and familial weight history; the Multi-Dimensional Body-Self Relations Questionnaire (MBSRQ; Brown, Cash, & Mikulka, 1990; Cash, 2000) as a measure of body image; questions about hunger levels during the experiment; the Weight Locus of Control scale (WLOC; Saltzer, 1982); Yale Food Addiction Scale (YFAS; Gearhardt, Corbin, & Brownell, 2009); the Food Craving Inventory (FCI-II; White & Grilo, 2005; White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002); the Barratt Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995) as a measure of behavioural impulsivity; and the Power of Food Scale (PFS; Cappelleri et al., 2009; Lowe et al., 2009) as additional measures of food behaviour and attitudes. Finally, they completed the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) to assess level of physical activity.

Following completion of the questionnaire battery, participants' height and weight were measured, as well as their waist and hip circumferences, and they completed a post-experimental questionnaire assessing strategy use and perceptions of the experiment. In order to account for some of the inaccuracies in using BMI as a measure of obesity (e.g., a larger, but fit and muscular person might have the same BMI as a person carrying more adipose tissue at the same height), we also included a visual rating measure. Two research assistants covertly rated the adiposity of each participant on a scale from one to ten, with ten being the most adipose. The inter-rater reliability of this measure was .86 in this sample.

Results

Weight Group Analysis

We first considered overall performance in both the ignore and forget tasks together in one analysis. This analysis indicated that the ignore task was easier than the forget task, but did not suggest a weight group by task interaction. Specifically, an ANOVA on overall task accuracy revealed no main effect of weight group, $F < 1$, $p > .9$, $\eta_p^2 < .001$, a main effect of task, $F(1, 54) = 32.36$, $p < .0001$, $\eta_p^2 = .375$, and no interaction between them, $F < 1$, $p > .4$, $\eta_p^2 = .011$. The main effect of task was due to the ignore task (*M* = 96.5%, *SD* = 0.48%) being easier than the forget task (*M* = 92.7%, *SD* = 0.69%). An ANOVA on overall task RT revealed no main effect of group, $F < 1$, $p > .4$, $\eta_p^2 = .010$, a main effect of task, $F(1, 54) = 21.76$, $p < .0001$, $\eta_p^2 = .287$, and an interaction between task and group that approached significance, $F(1, 54) = 3.10$, $p = .08$, $\eta_p^2 = .054$. The main effect of task was due to RTs in the forget task (*M* = 592.12, *SE* = 14.30) being significantly longer than RTs in the ignore task (*M* = 546.22, *SE* = 10.02). Finally, we compared the final bonus scores assigned to participants based on speed and accuracy across both tasks, and found no significant difference between normal weight (*M* = 373.39, *SD* =

145.45) and overweight/obese individuals (M = 390.57, SD = 146.84), $t(54) = -0.44$, $p > .65$, d = .118. We now turn to analyses examining each task individually. See Tables 3.2 and 3.3 for accuracy and RT data by weight group and dieting status, respectively.

Ignore data. Analysis of the ignore task data indicated no differential performance effects between the two weight groups in overall performance measures. This is consistent with our previous results showing no overall impairment in working memory item-recognition task performance in overweight/obese individuals. An ANOVA on accuracy data including probe category (food vs. country) and probe type (lure, negative, positive) showed no main effect of group or category, both $F < 1$, $p > .4$, no interaction between category and group, $F(1, 54) = 1.06$, $p > .3$, $\eta_p^2 = .019$. There was a main effect of probe type, $F(2, 108) = 5.73$, $p < .01$, $\eta_p^2 = .096$, and a probe type by group interaction, $F(2, 108) = 3.56$, $p < .04$, $\eta_p^2 = .062$. There were no other interactions, both $F < 1$, both $p > .4$. The main effect of probe type was due to negative probes being more accurate than either lures or positive probes overall, both $t(55) = 2.51$, both $p > .02$. The interaction between probe type and group was due to overweight individuals being more accurate than normal weight subjects on negative probes, but less accurate on lures and positive probes. These individual comparisons were not significant, all $|t|(54) < 1.3$, all $p > .2$. Planned comparisons also showed no significant differences between any probe type regardless of category, although it was food lure probe accuracy that came closest, $t(54) = 1.64$, $p = .11$, d = .439.

An ANOVA on RT data including probe category and probe type showed only a main effect of probe type, $F(2, 108) = 33.28$, $p < .0001$, $\eta_p^2 = .381$. No other main effects or interactions were significant, all $F < 1.3$, all $p > 0.2$. The main effect of probe type was due to positive probes being significantly faster than both negatives and lures, and negative probes being faster than lures, all $t(55) > 2.2$, all $p < .04$. Planned comparisons also showed no significant differences between any probe type regardless of category, all $|t|(54) < 1$, all $p > .4$.

We then examined interference scores, and again, this analysis indicated no difference in performance between the two weight groups. Interference scores were included in an ANOVA with group and category as independent variables. This analysis revealed no significant effects, all $F < 1$, all $p > .3$. Planned comparisons showed no group differences between food or country interference, both $|t|(54) < 1.4$, both $p > .18$, and no differences within subjects for either food or country interference, both $|t|(27) < 1.04$, both $p > .3$. Thus, the ignore task yielded no evidence of food-specific or generalized difficulty in resisting interference from ignored items, nor was there any evidence of generally slowed or inaccurate performance in overweight/obese individuals.[12] See Figures 3.2 and 3.3 for interference score data.

Forget data. We examined overall RT and accuracy in the forget task, and again detected no impaired performance in the overweight/obese group, again consistent with previous results showing no consistent general impairment in working memory item recognition task performance in overweight/obese individuals. Specifically, an ANOVA on accuracy data including probe category and probe type showed no main effect of group or category, both $F < 1$, $p > .5$.There was a main effect of probe type that failed to reach significance, $F(2, 108) = 2.23$, $p = .11$, $\eta_p^2 = .040$, and no other significant interactions, all $F < 1.9$, all $p > .15$. Planned comparisons also showed no significant differences between any probe type regardless of category, all $|t|(54) < 1.4$, all $p > .18$.

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[12] Using combined accuracy and RT interference z-scores in an ANOVA with group and category, results showed a main effect of group, $F(1, 54) = 5.69$, $p < .03$, $\eta_p^2 = .095$, and no other effects, $p > .8$. Planned comparisons revealed that overweight participants had numerically higher interference z-scores for food, $t(54) = -1.46$, $p = .15$, $d = -.395$, as well as countries, $t(54) = -1.80$, $p < .08$, $d = -.491$. Neither overweight nor normal weight participants showed higher interference within group for foods or countries, both $p > .8$.

An ANOVA on RT data including group, category, and probe type showed only a main effect of probe type, $F(2, 108) = 24.75$, $p < .0001$, $\eta_p^2 = .314$, all other $F < 1.7$, all $p > .2$. The main effect of probe type was due to positive probes being faster than negative and lure probes, and negative probes being faster than lure probes, all $t(55) > 2.9$, all $p < .01$. Planned comparisons revealed no significant differences between groups in any probe type regardless of category, all $|t|(54) < 1.7$, all $p > .09$.

We then examined interference scores to assess the hypothesis that volitional removal of food-related information from working memory would be compromised in overweight/obese individuals. These analyses indicated that although there were no significant group differences in performance, only the overweight/obese group had significantly more interference from food lures compared with country lures. Interference scores were included in an ANOVA with group and category as independent variables. This analysis revealed no main effect of group, $F < 1$, $p > .8$, $\eta_p^2 = .001$, a marginally significant main effect of category, $F(1, 54) = 3.40$, $p = .07$, $\eta_p^2 = .059$, and no interaction, $F < 1$, $p > .4$, $\eta_p^2 = .009$. Planned comparisons showed no group differences in either probe category, both $|t|(54) < 1$, both $p > .5$, and no difference between food and place interference for normal weight subjects, $t(27) = 0.72$, $p > .4$, $d = .137$. However for overweight subjects, food interference was significantly greater than place interference, $t(27) = 2.10$, $p < .05$, $d = .404$. Thus, only overweight/obese individuals showed differential susceptibility to food proactive interference from to-be-forgotten items, compared to their own ability to discard food-neutral to-be-forgotten items. These interference results are partially consistent with our hypothesis that there would be a food-specific vulnerability to task-intrinsic distraction in the overweight/obese group only.[13]

[13] Using combined accuracy and RT interference z-scores in an ANOVA with group and category, results showed no main effects, interactions, or planned comparisons, all $p > .3$.

Dieting Status Analysis

As our recent probes study had indicated current dieting to be a powerful influence on susceptibility to interference from task-intrinsic distraction, we completed a similar analysis with our ignore and forget task data. To analyze the influence of current dieting status on performance, we used responses to one item on the MBSRQ which read "I am on a weight loss diet." Participants rated their agreement with this item on a scale from one to five. We grouped anyone responding three or higher as current dieters, and the others as current non-dieters. This gave us a sample of 14 dieters and 41 non-dieters. One participant had not answered the dieting question and is therefore excluded from the analyses below.

We first examined overall performance, and found no indication that current dieters performed more poorly overall in either task. An ANOVA on overall task accuracy revealed no main effect of diet group, $F < 1$, $p > .4$, $\eta_p^2 = .011$, a main effect of task, $F(1, 53) = 23.44$, $p < .0001$, $\eta_p^2 = .307$, and no interaction between them, $F < 1$, $p > .6$, $\eta_p^2 = .003$. The main effect of task was due to higher accuracy in the ignore task (*M* = 96.5%, *SE* = 0.49%) than in the forget task (*M* = 92.6%, *SE* = 0.69%). An ANOVA on overall task RT revealed no main effect of group, $F < 1$, $p > .5$, $\eta_p^2 = .008$, a main effect of task, $F(1, 53) = 17.73$, $p < .0001$, $\eta_p^2 = .251$, and no interaction, $F < 1$, $p > .6$, $\eta_p^2 = .005$. The main effect of task was due to RTs in the forget task (*M* = 594.18, *SE* = 14.41) being significantly longer than RTs in the ignore task (*M* = 547.48, *SE* = 10.12). We then examined the data from the ignore and forget tasks separately.

Ignore data. Our analysis on RT and accuracy data in the ignore task also revealed no indication that current dieting influenced performance negatively in either speed or accuracy measures. Specifically, an ANOVA on accuracy data including diet group, probe category, and probe type revealed no main effect of diet group, $F < 1$, $p > .4$, $\eta_p^2 = .012$, a main effect of category that did not reach significance, $F(1, 53) = 3.10$, $p = .08$, $\eta_p^2 = .055$, a category by diet group interaction that approached significance, $F(1, 53) = 3.67$, $p = .06$, $\eta_p^2 = .065$, a main effect of probe type, $F(2, 106) = 4.18$, $p < .02$, $\eta_p^2 = .073$, and no other significant interactions, all $F <$ 1.9, all $p > .17$. The main effect of probe type was due to lures and positive probes being significantly less accurate than negative probes, both $|t|(54) > 2.4$, both $p < .02$. The category by diet group interaction may have been driven by a trend towards dieters having lower accuracy on ignore country trials, $t(53) = -1.54$, $p = .13$, $d = -.476$, as no other group differences in overall probe category accuracy in either task approached significance, all $|t|(53) < 1$, all $p > .6$. Finally, planned comparisons showed no significant diet group differences in any probe type in either category type in either task, all $|t|(53) < 1.4$, all $p > .17$.

An ANOVA on mean RT data showed no main effect of diet group or category, and no interaction between them, all $F < 1$, all $p > .3$. There was a main effect of probe type, $F(2, 106) = 25.27$, $p < .0001$, $\eta_p^2 = .323$, and no other significant interactions, all $F < 1$, all $p > .7$. The main effect of probe type was due to lure probes being slower than both negative and positive probes, and negative probes being slower than positive probes, all $t(54) > 2.2$, all $p < .03$. Planned comparisons showed no significant differences between dieters and non-dieters in any probe type, in any category type, all $t(53) < 1$, all $p > .5$.

We conducted an analysis on interference scores, and contrary to our hypothesis, there was no effect of current dieting status in the ignore task. An ANOVA including diet status and category on interference scores showed no main effects or interactions, all $F < 1$, all $p > .5$. Planned comparisons showed no significant differences between groups, or within subjects, all $|t| < 1$, all $p > .5$.[14]

[14] Using combined accuracy and RT interference z-scores also yielded no main effects, interactions, or planned comparisons, all $p > .7$.

Forget data. We again examined overall RT and accuracy measures in the forget task, and again found no influence of current dieting on performance in either performance metric. An ANOVA on accuracy data showed no main effects of diet or category, both $F < 1$, $p > .8$, and no interaction between those two variables, $F < 1$, $p > .7$, $\eta_p^2 = .002$. There was a main effect of probe type, $F(2, 106) = 3.75$, $p < .03$, $\eta_p^2 = .066$, a probe type by diet group interaction that failed to reach significance, $F(2, 106) = 1.78$, $p = .17$, $\eta_p^2 = .033$, no category by probe type interaction, $F < 1$, $p > .5$, $\eta_p^2 = .012$ and a three-way category by probe type by dieting status interaction that approached significance, $F(2, 106) = 2.51$, $p < .09$, $\eta_p^2 = .045$. The main effect of probe type was due to negative probes being the most accurate, followed by lures and then positive probes, but the only paired comparison to approach significance was the comparison between negative and positive probes, $t(54) = 1.87$, $p < .07$. Planned comparisons revealed only one significant diet group difference with dieters having significantly lower accuracy on positive food probes, $t(53) = -2.25$, $p < .03$, $d = -.704$.

An ANOVA on mean RT data showed only a main effect of probe type, $F(2, 106) = 15.81$, $p < .0001$, $\eta_p^2 = .230$, all other $F < 1.4$, $p > .25$. This main effect of probe type was due to lures being slower than negative and positive probes, and negative probes being slower than positive probes, all $t > 3.0$, all $p < .01$. Planned comparisons showed no significant diet group differences on any probe type within either category, all $|t| < 1.2$, all $p > .2$.

We then turned to the interference score analysis, and once more found no effect of current dieting status, results inconsistent with our hypothesis that current dieting would negatively influence the ability to volitionally remove food information from working memory. An ANOVA on interference scores including diet group and category as factors showed no main effect of diet group, $F < 1$, $p > .8$, $\eta_p^2 = .001$, a main effect of category that failed to reach significance, $F(1, 53) = 2.54$, $p < .12$, $\eta_p^2 = .046$, and no interaction, $F < 1$, $p > .9$, $\eta_p^2 < .001$. Planned comparisons showed no significant differences within subjects or between groups, all $|t| < 1.6$, all $p > .14$.[15]

Overall, our analysis of current dieting status as a variable of interest revealed that our hypothesis that dieters would show some deficit in the ability to guard working memory against food-related information was unsupported. Indeed, no metric indicated that dieters were performing more poorly, and this was true in both tasks.

Correlational Analyses

Though to this point, BMI and dieting status have been treated as dichotomous variables, these variables can be considered continuous dimensions, and in our recent probes study, several measures were moderately well-correlated with task performance metrics. We therefore conducted a similar analysis using the interference scores from the ignore and forget tasks. In order to evaluate the degree to which dieting and obesity were related to performance in the ignore and forget tasks, correlations were computed between interference scores and several questionnaire variables of interest hypothesized to best capture the dimensions of obesity and dieting behaviour. BMI, waist to hip ratio, and average participant adiposity ratings were used to reflect the degree to which a participant was overweight. Additionally, item 57 of the MBSRQ, which asked participants to state on a scale from 1 to 5 how strongly they agree with the statement “I am on a weight loss diet,” was included as an index of current dieting behaviour. Total scores on the Restraint Scale, and the uncontrolled eating, emotional eating, and cognitive restraint subscales of the TFEQ were used, along with the restraint, external eating, and emotional eating subscales of the DEBQ as indices of long-term dieting and eating behaviour.

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[15] Using combined accuracy and RT interference z-scores yielded no significant main effects, interactions, or planned comparisons, all $p > .5$.

The overweight preoccupation factor subscale of the MBSRQ was used as an index of how much participants worried about being or becoming overweight. YFAS symptom count was used as a metric of addictive behaviour with food, and FCI total scores were included as an index of craving. We hypothesized that BMI, waist to hip ratio, and adiposity ratings would be related to food interference. We also hypothesized that dieting, dietary restraint, and overweight preoccupation would be correlated with food interference, based on previous results. In the current sample, we were also able to assess the relationship between food addiction symptoms and food craving metrics (YFAS, FCI and PFS scores), and hypothesized that these variables would also be positively correlated with food interference. Finally, we included the external, emotional, and uncontrolled eating subscales of the TFEQ and DEBQ in an exploratory fashion, and applied a Bonferroni correction to those tests.

Despite previous results indicating that dieting, restraint, overweight preoccupation, and objective measures of obesity can be related to cognitive task performance, there was no evidence of any such relationship in the present data. Ignore food and ignore country interference scores were not significantly correlated with any measure, all $|r| < .25$, all $p > .06$, nor were forget food and forget country interference scores, all $|r| < .23$, all $p > .09$.

Discussion

The present results showed no evidence of a selective attention deficit or attentional bias in the ignore task in the overweight/obese group. However, there was some evidence that intentional removal of information from working memory in the forget task was more difficult for food information than place information, in the overweight/obese group only. Considered together with our previous evidence that overweight/obese individuals experience increased interference from food-related information in working memory, the available evidence suggests a food-specific vulnerability in the control of the contents of working memory, even in a task where explicit instruction to remove information from mind was presented. Notably, both the recent-probes task and the forget task require that food information be encoded and then discarded. In contrast, the ignore task requires that some food information be completely barred from working memory. This difference seems to be important, as the ignore task revealed no significant effects, while the recent probes and forget tasks each suggest the possibility of a compromised food-specific cognitive control process in working memory.

The results of the forget task indicated that for overweight/obese participants, removal of food words from mind was more difficult than removing place words from mind. The results of the ignore task indicated that there was no such difference when food words did not need to be encoded in the first place. That is, there was no evidence of a deficit in controlling attention to food words—with instructions to ignore food words, participants were not adversely affected by the food-related content. Only when food words had to be encoded into working memory, as in the forget task, and then removed from the focus of attention, in order to perform the task accurately, was the food-related nature of the stimuli problematic. Considered in the context of our previous results using the recent-probes task, wherein food information needed to be encoded and then discarded when no longer relevant, the results from our working memory studies suggest that the nature of cognitive control difficulties in working memory that may be attributable to obesity is in deleting information from working memory, not preventing its access (see Hasher et al., 1999; Lustig et al., 2007).

Previous research has established some form of attentional bias to food cues (e.g., Hou et al., 2011; Nijs et al., 2010; Overduin et al., 1995; Yokum et al., 2011) in both overweight/obese individuals and in individuals exercising a high degree of dietary restraint. Both theories of incentive sensitization (e.g., Berridge, 1996; Berridge et al., 2010) and increased externality in obesity (e.g., Herman, Polivy, Pliner, Threlkeld, & Munic, 1978; Rodin, 1973; Schachter, 1971; Schachter & Gross, 1968) would suggest that increased sensitivity to food-related information could manifest in a difficulty in attentional control. However, our results are not consistent with the existence of such an effect[16]. The absence of such an effect in the present study, combined with previous failures to find such specific effects suggest that there are limits to the attentional bias to food, or that there may be moderating factors, such as hunger[17] (e.g., Gearhardt et al., 2012; Nijs et al., 2010; Tapper et al., 2010). A study by Higgs and colleagues (Higgs, Robinson, & Lee, 2012) showed that an attentional biasing effect towards food was only found when food information was held in working memory, which is consistent with our results, and may be key to finding such effects. If individuals have food-related information in mind because of weight and shape concerns, hunger, or craving, for example, one might see attentional bias. However, if instructed to keep food information out of mind and to prevent the encoding of food information, as in our ignore task, in the absence of these states or traits, this attentional bias may not manifest. One potential future direction could be to magnify differences in the incentive salience value of food stimuli in participants in advance of performing the ignore and forget tasks. Prompting individuals to think about how much they want a food item, how good it would taste,

[16] To assess whether or not the present experiment was adequately powered to detect attentional bias effects, should they exist, effect sizes from previous comparisons of normal weight and overweight, or restrained and unrestrained eaters were calculated from previously published reports. With Cohen's *d* values ranging between .42 and 1.57, power analyses using G*Power 3.1 (Faul, Erdfelder, Lang & Buchner, 2007) indicated between 8 and 89 subjects per group would be required to detect the effect of interest with .80 power. Though our 32 subjects per group design was adequately powered to detect effects according to some effect sizes from previous studies, these were typically eye tracking measures, while RT measures yielded smaller effects requiring more participants to achieve .80 power. It thus remains unclear whether or not our current sample was large enough from a power perspective.

[17] Subjective hunger ratings collected from participants at the end of the experiment asking about current hunger levels and hunger levels at the beginning of the testing session were not related to interference in the ignore or forget task in either semantic category (all $|r| < .25$, all $p \geq .07$).

and so on, before performance of the ignore task could make it more difficult to control attention. Such a manipulation could potentially increase any food-selective attentional bias by introducing food information into working memory before the task, increasing the likelihood of problematic management of the contents of working memory. Additionally, our sample contained only three participants meeting criteria for food addiction (Gearhardt et al., 2009; 2012). In a sample with more prevalent food addiction symptomatology, a sample more sensitized to food, or with an experimental paradigm in which actual opportunity for food acquisition or consumption was more proximate, perhaps we might see stronger effects. Finally, performing the tasks in a food-cue-rich environment could also magnify any small effects. The present experiments were conducted in a neutral lab environment, but simulating the intense food cues that are encountered on a daily basis in restaurants, shops, and media could lend more ecological validity to our findings and perhaps foster the emergence of effects that are elicited by actual food cues.

Additionally, the design of our tasks was such that both negative and lure probes always contained stimuli from the to-be-ignored or to-be-forgotten category, which ensured that the interference effect we calculated controlled for semantic interference (since both probe types had matching semantic categories). In our recent probes experiment, semantic interference had the strongest effect, so it is possible that by using an interference metric that controlled for semantic interference, we minimized effects that might have otherwise been detected.

This last point is also relevant for the forget task results. Although there was a significant difference between the interference caused by food lures versus country lures in the overweight/obese group, the type of between-groups effect that we had seen in the recent-probes task was absent here. Perhaps the way the interference effects were calculated, using matching category probes, was a contributing factor. In our recent-probes task, we displayed all four stimuli in one category on each trial (e.g., four foods or four countries). Conversely, in the ignore and suppress tasks in this experiment, we used two stimuli from each category in an effort to pit the two categories against each other. However, this also had the consequence of increasing the set differentiation between items to remember and items to ignore or forget. That is, the two items to ignore or forget were semantically related, presented in the same colour, and distributed diagonally across the screen. Since one hypothesized mechanism for successful directed forgetting task completion is set differentiation (Bjork, 1972; Bjork & Geiselman, 1978; Horton & Petruk, 1980), we may have minimized the magnitude of the effects we detected. Restructuring the task to include four items of one category on screen at one time, and including negative probes from mismatching categories could remedy this problem in future studies.

Our hypothesis about increased BMI being inversely related to performance in the food-related context of this task was at least partially supported. In contrast, our hypothesis about dieting and associated weight preoccupation, based in part on the strong results in our recent probes study, was unsupported by the current data in either the ignore or forget task. There were no significant effects when using dieting status as a dichotomous variable, nor were there any significant correlations between measures of food-related behaviour and task performance. The explanations offered above for the overall subtlety of the effects may also apply to these correlational analyses.

Overall, the results suggest that even when explicitly instructed to remove food information from working memory, whether performance under such instruction is achieved through active inhibition, set differentiation, or some other process, difficulties with task-intrinsic distraction remain in overweight/obese participants. This is especially interesting, considering the somewhat mixed literature on the efficacy of thought suppression to reduce food and other types of craving (e.g., Barnes & Tantleff-Dunn, 2010; Erskine & Georgiou, 2010; Forman et al., 2007; Hooper, Sandoz, Ashton, Clarke, & McHugh, 2012; Kober et al., 2010), with some studies finding instructions to suppress thoughts of food effective, and others finding the opposite. However, one might also point out that although it is difficult to compare the recent probes and directed forgetting tasks, the results in the recent-probes task were perhaps stronger, as indicated by slightly larger effect sizes, suggesting that the forget instruction was successful in some sense. We may conclude that this active control over the contents of working memory is only selectively affected in overweight/obese individuals. That is, once again, our results in these working memory tasks are inconsistent with previous reports of generalized executive control deficits, and instead suggest that at least in the working memory domain, content matters. Future studies can further delineate the effective limits of this content specificity and identify conditions which maximize or minimize its effect. Future work should also focus on reconciling the absence of attentional bias effects documented here, with previously published reports of such attentional bias. We suggest that the control over the contents of working memory may be an important determinant of the presence or absence of such effects. Finally, experiments targeting active control over the contents of working memory and its potential ability to be trained can ascertain the extent to which applying such control is productive for real-world applications such as craving regulation, diet adherence, weight loss maintenance, or control of pathological wanting processes in addictive-like behaviour with food.

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Table 3.1 Participant characteristics by weight group and dieting status

	Normal Weight	Overweight	Dieter	Non-Dieter
N	28	28	14	41
Age	19.7 (1.4)	19.2 (1.4)	19.2 (1.3)	19.5 (1.4)
Percent Female	53.57%	53.57%	71.43%	46.34%
Years of Education	13.9 (1.4)	13.5 (1.3)	13.2 (1.3)	13.8 (1.4)
BMI	21.7 (2.1)	30.2 (3.2)***	27.9 (4.2) †	25.1 (5.2)
Average Adiposity Ratings	1.9 (0.5)	3.2 (0.7)***	2.8 (0.7)	2.4 (0.9)
DEBQ Restraint	2.19 (0.17)	2.89 (0.13)**	3.47 (0.12)***	2.19 (0.11)
DEBQ External Eating	3.39 (0.08)	3.28 (0.11)	3.42 (0.12)	3.30 (0.08)
DEBQ Emotional Eating	2.09 (0.14)	2.59 (0.15)*	2.84 (0.23)**	2.15 (0.11)
TFEQ Uncontrolled Eating	2.20 (0.09)	2.29 (0.08)	2.59 (0.11)**	2.14 (0.06)
TFEQ Cognitive Restraint	2.38 (0.17)	2.92 (0.10)**	3.28 (0.13)***	2.40 (0.11)
TFEQ Emotional Eating	1.65 (0.11)	2.14 (0.15)*	2.29 (0.19)*	1.76 (0.11)
Overweight Preoccupation	2.07 (0.15)	2.65 (0.15)***	3.39 (0.15)***	1.98 (0.09)
Current Dieting Status	1.61 (0.21)	2.19 (0.27) †	3.86 (0.25)***	1.22 (0.07)
Restraint Scale Total	11.21 (1.06)	16.82 (0.89) ***	20.57 (0.82)***	11.66 (0.75)
YFAS Symptom Count	1.21 (0.15)	1.96 (0.34)*	2.71 (0.52)**	1.22 (0.15)
FCI Total	54.89 (2.80)	60.71 (2.58)	67.50 (3.04)**	54.90 (2.19)
BIS Total	60.79 (1.28)	62.18 (1.80)	64.43 (2.60)	60.76 (1.16)
PFS Total	2.43 (0.12)	2.45 (0.16)	2.81 (0.22)*	2.33 (0.11)

Note. Age, Years of Education, BMI, and Adiposity Ratings are *M* (*SD*). All other measures are *M* (*SE*). *** = $p < .0001$, ** = $p < .01$, * = $p < .05$., † = $p < .10$.

Table 3.2 Accuracy and RT data by weight group

	Normal Weight		Overweight	
	Accuracy (%)	RT (ms)	Accuracy (%)	RT (ms)
Forget Task				
Overall	92.50 (1.03)	609.28 (20.04)	92.89 (0.94)	574.97 (20.25)
Country Lure	93.75 (1.20)	640.33 (18.57)	92.57 (1.93)	602.46 (23.89)
Food Lure	91.50 (1.58)	647.90 (19.87)	92.57 (1.41)	606.80 (21.78)
Country Negative	92.07 (3.04)	625.36 (22.10)	96.46 (1.22)	589.59 (20.82)
Food Negative	93.57 (2.83)	623.84 (21.06)	96.96 (0.92)	574.00 (20.81)
Country Positive	92.29 (1.14)	584.03 (21.09)	91.50 (1.24)	556.37 (22.50)
Food Positive	92.86 (1.09)	584.61 (24.53)	91.36 (1.32)	557.83 (20.44)
Ignore Task				
Overall	96.82 (0.73)	546.04 (14.19)	96.18 (0.64)	546.41 (14.41)
Country Lure	95.64 (1.19)	563.80 (12.88)	95.43 (1.13)	564.42 (16.83)
Food Lure	97.82 (1.02)	568.76 (16.57)	95.43 (1.04)	565.68 (13.15)
Country Negative	96.96 (1.39)	564.64 (16.06)	98.71 (0.57)	548.90 (15.10)
Food Negative	97.39 (1.16)	557.29 (15.07)	98.50 (0.50)	556.37 (16.69)
Country Positive	97.00 (0.60)	532.36 (15.38)	95.46 (0.99)	537.01 (14.59)
Food Positive	96.75 (0.78)	524.93 (15.10)	95.43 (1.09)	531.17 (15.80)

Note. All measures are *M* (*SE*).

Table 3.3 Accuracy and RT data by dieting status

	Dieter		Non-Dieter	
	Accuracy (%)	RT (ms)	Accuracy (%)	RT (ms)
Forget Task				
Overall	92.14 (1.54)	611.61 (29.92)	92.71 (0.77)	588.23 (16.54)
Country Lure	91.71 (3.44)	637.14 (30.24)	93.49 (1.02)	620.08 (17.71)
Food Lure	93.50 (2.10)	638.58 (26.17)	91.34 (1.23)	625.84 (18.23)
Country Negative	96.43 (1.84)	625.82 (32.65)	93.39 (2.16)	604.31 (17.46)
Food Negative	97.86 (1.02)	612.40 (30.98)	94.27 (1.99)	595.50 (17.77)
Country Positive	90.79 (1.91)	602.71 (36.32)	92.07 (0.93)	562.80 (16.55)
Food Positive	88.79 (2.13)	587.59 (32.79)	93.05 (0.84)	567.65 (18.71)
Ignore Task				
Overall	95.57 (0.94)	556.31 (25.01)	96.78 (0.57)	544.47 (10.74)
Country Lure	94.36 (1.64)	577.23 (28.96)	95.83 (0.96)	562.27 (10.26)
Food Lure	97.86 (1.02)	579.77 (23.27)	96.27 (0.94)	564.19 (11.96)
Country Negative	96.14 (1.19)	562.86 (26.15)	98.37 (0.94)	556.98 (12.02)
Food Negative	98.29 (0.75)	567.89 (27.38)	97.78 (0.83)	554.08 (12.15)
Country Positive	94.86 (1.15)	540.51 (24.18)	96.68 (0.69)	534.28 (11.81)
Food Positive	94.50 (1.84)	541.19 (27.74)	96.61 (0.66)	525.14 (11.44)

Note. All measures are *M* (*SE*).

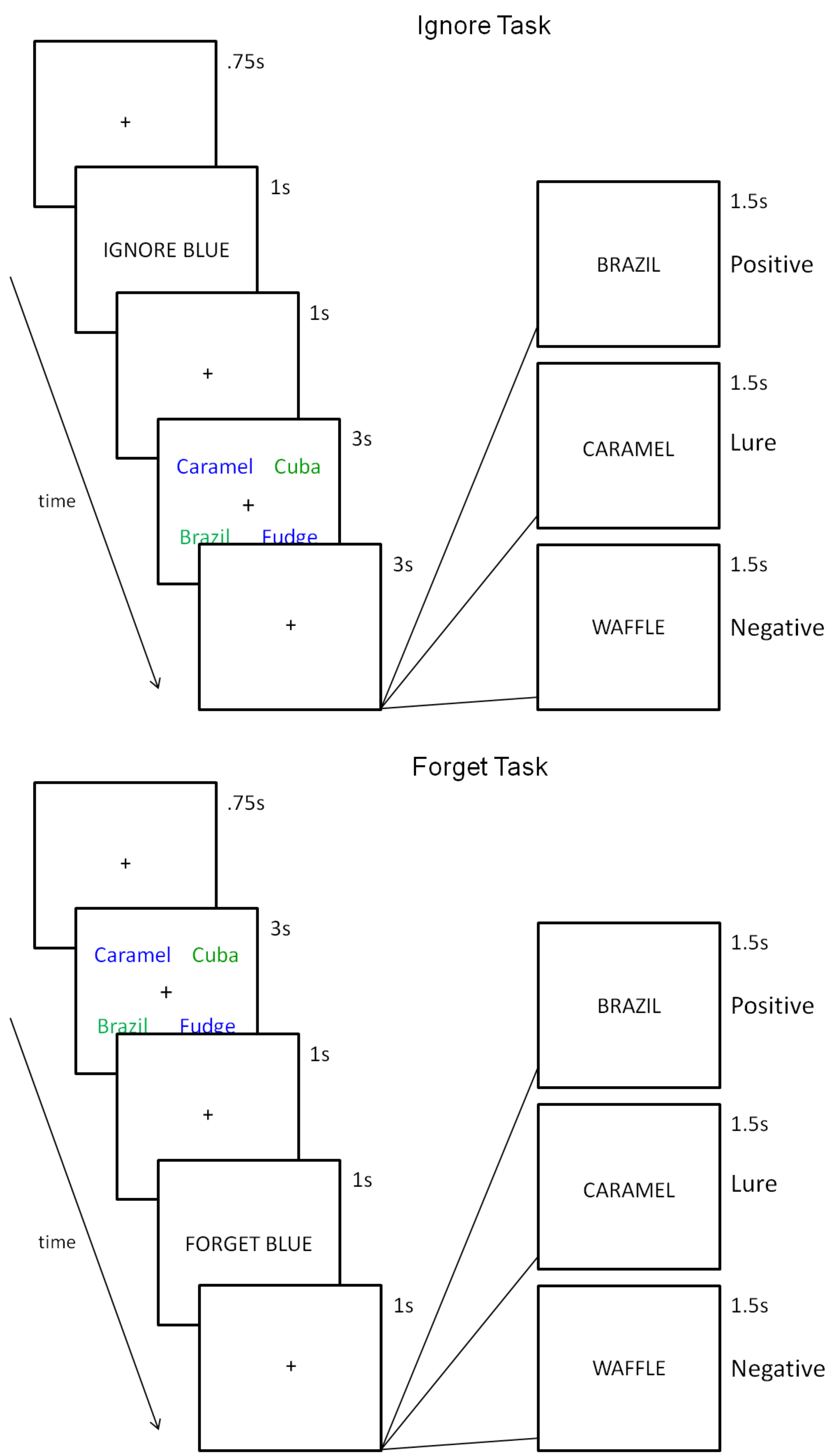

Figure 3.1 Task diagrams for example ignore and forget trials.

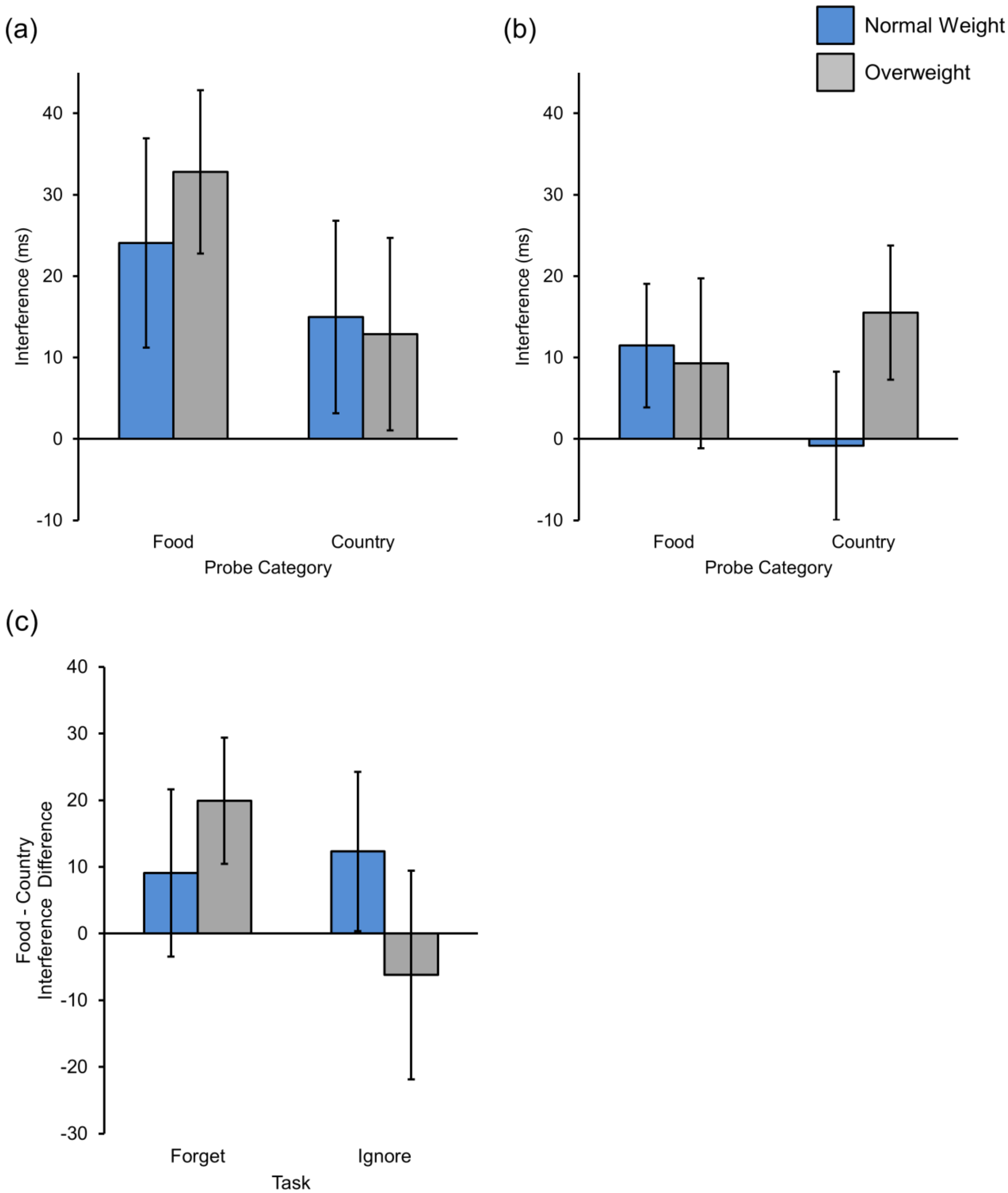

Figure 3.2 Interference scores by weight group (a) in the Forget task, (b) in the Ignore task, (c) Food – Country interference difference (within subjects comparison).

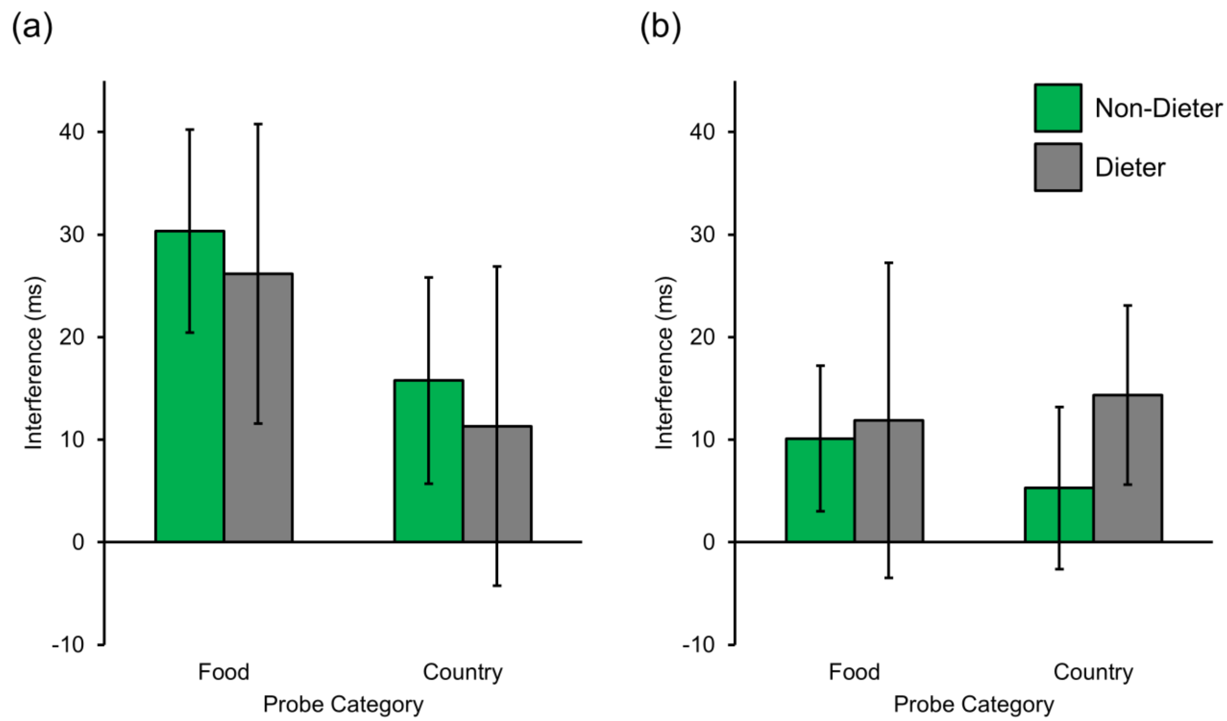

Figure 3.3 Interference scores by dieting status (a) in the Forget task, (b) in the Ignore task.

CHAPTER IV

Task-Extrinsic Distraction in Sustained Attention

Introduction

Previous studies of obesity and cognition have often focused on broad cognitive deficits (see Smith, Hay, Campbell, & Trollor, 2011 for a review). Conversely, specific cognitive control processes may be affected by excess weight or could otherwise be important for weight regulation. One such cognitive control process is the ability to direct attention to a task for a long period of time. Sustained attention is a fundamental component of the human attentional system, often conceptualized as the maintenance of an alert state (Posner, 1994; Posner & Boies, 1971), contrasted with more transient attentional processes (Nakayama & Mackeben, 1989). Sustained attention is a type of attentional management that requires active, goal-directed management to avoid succumbing to distraction (Pardo, Fox, & Raichle, 1991; Posner & Petersen, 1990), and in this sense is thought to require cognitive control.

Sustained attention tasks (also referred to as vigilance tasks) typically involve the detection of rarely occurring signals that are presented unpredictably over long periods of time. Often a decline in performance over time, referred to as the "vigilance decrement," occurs (Parasuraman, 1979), involving lower rates of correct responses. This performance decrement has been linked to decreased activation in task-relevant brain networks and increased activation in task-irrelevant or default-mode brain networks (e.g., Paus et al., 1997; Weissman, Roberts, Visscher, & Woldorff, 2006). Evidence from human and animal studies implicates the cholinergic system as being necessary for effective sustained attention performance, particularly when sustained attention processing is further challenged by the presence of distraction (e.g., Sarter, Givens, & Bruno, 2001). Importantly, sustained alertness is conceptualized as supporting detection and selection components of attention, but is distinct from these processes. Sustained attention has been measured with tasks including the CPT, where letters are presented one at a time and participants respond to target letters or letter combinations (Rosvold, Mirsky, Sarason, Barnsome, & Beck, 1956), the SART, where digits are presented one at a time and participants respond to all digits except the designated target digit (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) the RVIP, where digits are presented one at a time and participants respond to target sequences of consecutive digits (e.g., Lawrence, Ross, Hoffmann, Garavan, & Stein, 2003; Wesnes & Warburton, 1983), the CTET, where participants must detect a lengthened timing interval between presentations of black and white grids, which change at predictable timing intervals (O'Connell et al., 2009) and the dSAT, explained in detail below (Demeter, Sarter, & Lustig, 2008), for example. These tasks have common elements of unpredictably occurring target events that are often difficult to discriminate from non-targets (sometimes because their status as target is dependent on contextual features), and participants are asked to perform the tasks for extended periods of time, although these range from a few minutes to the better part of an hour.

In order to uphold focus on short-term or long-term weight control goals, one important mental capacity may be the ability to resist distraction from task-extrinsic or external stimuli while trying to maintain attention to a task. It is common in popular culture to make statements about the need for vigilance, diligence, or prolonged focus in a dieting program to ensure success. This popular conception of weight regulation contains an implicit assumption that sustaining attention to dieting goals and avoiding distraction from them in the form of temptation is required for weight regulation success. In other words, there is an assumption that individuals who have difficulty controlling their weight are lacking in sustained attention capacity. This popular conception of the mental abilities required to effectively regulate weight is largely untested. The cognitive control demands imposed by many sustained attention also tasks provide a possible test case for the hypothesis that control over attentional focus is important to weight regulation. Introducing irrelevant distraction that must be ignored further challenges the cognitive control abilities required to direct and maintain attention over an extended period of time. We propose to extend our previous exploration of distractibility in the working memory domain by testing the hypothesis that compromised cognitive control in sustained attention may be related to obesity.

Previous research relating attention to weight regulation has largely focused on selective attention or orienting. For example, investigators have documented an increased attentional bias to food in dot-probe tasks, adapted attention network tasks, Stroop tasks, or visual search tasks (e.g., Brignell, Griffiths, Bradley, & Mogg, 2009; Castellanos et al., 2009; Gearhardt, Treat, Hollingworth, & Corbin, 2012; Hou et al., 2011; Mobbs et al., 2011; Nijs, Muris, Euser, & Franken, 2010; Nijs, Franken, & Muris, 2009; Nummenmaa et al., 2011; Overduin et al., 1995; Smeets et al., 2009; Smith & Rieger, 2006; Yokum, Ng, & Stice, 2011), though studies have not always found evidence of altered early attentional selection processing specific to overweight/obese individuals (e.g., Loeber et al., 2012; Mobbs et al., 2011; Nijs et al., 2010). Investigations of sustained attention in relation to weight regulation and obesity specifically have been scarcer. In the work that has been conducted, there have been documentations of impaired monitoring in dieters, (Ward & Mann, 2000), poorer self-described vigilance in dieters (Byrne, Cooper, & Fairburn, 2003), and impaired alertness in obese individuals with hypoventilation syndrome (Chouri-Pontarollo et al., 2007), though it is not clear that this result was directly related to obesity. Additionally, studies assessing the effects of dieting and weight loss on cognition have documented poorer sustained attention in dieters (measured by a visual variant of the Bakan vigilance task, wherein participants are presented with digits one at a time in the auditory modality and must respond to target sequences of digits; Bakan, 1961; Williams et al., 2002). This is potentially a direct effect of lowered iron levels, as several measures of iron have been related to impaired sustained attention in dieters (Kretsch, Fong, Green, & Johnson, 1998). However, there has also been failure to find an effect of dieting on sustained attention (Green, Elliman, & Rogers, 1997; Kretsch, Green, Fong, Elliman, & Johnson, 1997), and in children, sustained attention performance, unlike other measures of cognitive and emotional regulation, has not been shown to predict later obesity (Graziano, Calkins, & Keane, 2010). Finally, sustained attention abilities measured by the d2 attention task (described in the paragraph below; Bates & Lemay, 2004; Brickenkemp & Zillmer, 1998) have been shown to be poorer in obese women (Cserjési, Luminet, Poncelet, & Lénárd, 2009).

These investigations together suggest that dieting may be associated with compromised sustained attentional abilities, and hint at the possibility that sustained attention abilities in obesity may also be compromised. However, the d2 task used in the only study to examine sustained attention in obesity *per se* has also been suggested as a test of visual scanning and speed, as it requires participants to identify and cancel out target letters in an array of similar letters. The d2 task has been shown to correlate with performance on other executive function tasks like Stroop and Trail Making, and although it is clear the task has attentional demands, it does not conform to the typical parameters associated with sustained attention/vigilance task such as those described above.

Theories of food addiction (see Berridge, 2007; 2009; Gearhardt et al., 2012; Volkow & Wise, 2005; Wang et al., 2004) suggest that for individuals who have developed a highly sensitized response to food (incentive sensitization), food stimuli should be very powerful cues drawing attention away from other stimuli in the environment. Theories of heightened external responsiveness (Herman, Polivy, Pliner, Threlkeld, & Munic, 1978; Rodin, 1973; Schachter, 1971; Schachter & Gross, 1968) also suggest that obese and dieting individuals may have heightened responses to external stimuli, and if that is the case with distraction, they may be more vulnerable to performance disruption as a result of attentional capture by distractors.

To our knowledge, there have also been no studies of sustained attention specifically examining susceptibility to task-extrinsic distractors in obesity or dieting. Resisting distraction is an important test of cognitive control in the sustained attention domain. Though successfully maintaining attention to a target or goal is presumably important on an abstract level for adhering to a weight management program or lifestyle, maintaining this type of attentional focus when confronted with potentially disruptive, irrelevant information is a more realistic assessment of the control abilities required in real-world tasks. The ability to maintain attention in the face of a monotonous, repetitive task also requires resistance to internal, mind-wandering-type distractions. Even if sustained attention performance is normal in optimal, undisturbed circumstances, if performance falls apart under conditions of distraction, this could indicate a type of control disruption that has been linked to real-world consequences like attentional lapses and absent-mindedness (e.g., Barkley, 1997).

The following experiments were designed to determine whether or not there are obesity-related deficits in the ability to maintain sustained attention in the presence of distraction from task-extrinsic stimuli, and whether such deficits are exaggerated in the presence of food-related distraction. We hypothesized that higher BMI would be associated with poorer sustained attention performance, but only under the challenging conditions of distraction. We hypothesized that performance would be further impaired under food-related distraction conditions. We also hypothesized that dieting might be related to sustained attention performance. Specifically, we hypothesized that dieters would show poorer sustained attention performance under conditions of distraction, and that this effect would be exaggerated in the context of food-related content. In order to assess these hypotheses, the Sustained Attention Task (SAT) and its distractor condition (dSAT) were employed. These tasks require the maintenance of attention to a signal detection task, and the distractor condition introduces a highly salient perceptual distractor (Demeter et al., 2008; 2011). The task has an analogous version used in rodent studies (e.g., Bushnell, 1999; McGaughy & Sarter, 1995), and individuals with schizophrenia have been shown to perform more poorly specifically in the distraction condition (Demeter, Guthrie, Taylor, Sarter, & Lustig, 2013), indicating this task can be used to detect impairment in distractor resistance despite intact baseline sustained attention performance.

Ours is the first investigation to our knowledge to systematically assess sustained attention performance in a sample of overweight and lean adults including a distraction condition in which a task-irrelevant distraction manipulation is employed to challenge the maintenance of focal attention to the task at hand. We first assessed performance in a brief version of the SAT and its distractor condition (Experiment 1). We then assessed performance in a more prolonged experimental session (Experiment 2). Finally, we assessed performance with food-related and food-neutral distraction (Experiment 3).

Experiment 1

Method

Participants

Fifty-five young adults between the ages of 18 and 27 participated in the experiment. Two participants were excluded from analysis because they showed extremely poor performance with high numbers of non-responses during the baseline (no distraction) SAT condition, leaving no usable trials in multiple cells. This left a total sample of 53 participants. Weight groups (normal weight, overweight/obese) were defined by BMI cut-offs. BMI is a proxy measure of body fat calculated as a ratio of weight to height in kg/m^2. Groups were defined such that those in the normal weight group had BMI < 25, and those in the overweight/obese group had BMI ≥ 25. This yielded a sample of 29 normal weight and 24 overweight participants. All included subjects were healthy with no reported medical diagnosis or medication that would influence their weight. See Table 4.1 for participant characteristics.

Task

The task was programmed in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). The (d)SAT was a shortened version of the task employed by Demeter and colleagues (Demeter et al., 2013). In the task, $3.5mm^2$ signals (grey squares on a silver background) appeared in one of 3 locations on the computer screen. The three locations were centered, with the first location occurring at 30% of the vertical height of the screen, the second at 50% and the third at 70%. The signals appeared for one of three durations: 34, 50, or 150ms. The 34ms signals were twice as probable as the 50 and 150ms signals. There was a 50% probability of a signal occurring on any given trial. See Figure 4.1.

Each trial began with 1000, 2000, or 3000 ms of a blank silver screen—this time is referred to as the monitoring period, as participants must continuously monitor for signals during this variable duration of time. Each monitoring period was equally probable on any given trial.

Following the monitoring period, a signal appeared for one of the durations specified above. Five hundred milliseconds after a signal (or non-signal) occurred, participants were cued to respond by a short buzzer sound (approximately 300 ms in duration). Participants were given 1000 ms to respond, and received auditory feedback in the form of a short ringing sound if they responded correctly (also approximately 300 ms in duration). There was no feedback for incorrect responses or non-responses. Thus, participants were meant to respond to all trials, allowing the assessment of hits, false alarms, misses and correct rejections. Performance in this task was measured using a sensitivity index (d′) which is calculated using the proportions of hits and false alarms: $z(P_{Hits}) - z(P_{False\ Alarms})$. Higher d′ values indicate better performance, particularly sensitivity (Green & Swets, 1966). In this case, the maximum possible d′ score would be approximately 4.65, with subjects achieving a proportion of hits at .99 and proportion of false alarms at .01, while a d′ of 0 would be achieved if the proportions of hits and false alarms were equal.

In the distractor condition, the same task parameters applied, but the screen flashed from black to silver at 10 Hz throughout each trial, providing a highly salient perceptual distractor that was difficult to ignore. In the distractor condition, the signals always appeared on the silver screen, so the signal-to-background contrast was consistent with the no-distraction condition.

Procedure

After completing informed consent and a demographics survey, participants completed approximately one hour of other computerized tasks not relevant to the present analyses. Prior to completing the dSAT, participants also completed a battery of questionnaire measures, including the Rotter Locus of Control Scale (Rotter, 1966) as a measure of internal versus external control orientation; the Dutch Eating Behaviour Questionnaire (DEBQ; van Strien, Frijters, Bergers, & Defares, 1986), the Restraint Scale (Herman & Polivy, 1975; 1980), and the Three Factor Eating

Questionnaire (TFEQ; Stunkard & Messick, 1985) as assessments of eating behaviours and attitudes; personal and family weight history questions to assess individual and familial weight history; the Multi-Dimensional Body-Self Relations Questionnaire (MBSRQ; Brown, Cash, & Mikulka, 1990; Cash, 2000) and a version of the Body Image Assessment for Obesity (BIA-O; Williamson et al., 2000; Williamson, Gleaves, Watkins, & Schlundt, 1993) as measures of body image; questions about hunger levels during the experiment; and a subset of the participants completed the Yale Food Addiction Scale (YFAS; Gearhardt, Corbin, & Brownell, 2009) as an additional measure of food behaviour and attitudes.

Following completion of the questionnaire battery, participants' height and weight were measured. In order to account for some of the inaccuracies in using BMI as a measure of obesity (e.g., a larger, but fit and muscular person might have the same BMI as a person carrying more adipose tissue at the same height), we also included a visual rating measure. Two research assistants covertly rated the adiposity of each participant on a scale from one to ten, with ten being the most obese. The inter-rater reliability of this measure was .77 in this sample.

Finally, participants completed the dSAT at the end of the testing session. First, participants completed some practice in which the task was explained, and then the participants completed a brief version of each of the SAT and dSAT conditions (30 seconds each). Participants were instructed that they would have a brief time to respond to each trial, and that they would earn points for accurate responding. Each participant then completed a two-minute block of the SAT condition, then two, two-minute blocks of the dSAT condition, then a final two-minute block of the SAT condition. There were no breaks between the blocks of the task, so the entire task run lasted eight minutes.

It was hypothesized that overweight/obese individuals would perform more poorly on the dSAT blocks compared with their lean peers. It was also hypothesized that performance in the SAT blocks would not differ between groups. Finally, we expected that under the most challenging task conditions (e.g., shortest signal durations), the effects would be most pronounced.

Results

Non-Response Data

We first examined the proportions of trials on which subjects failed to provide any response (i.e., neither a correct nor incorrect response was recorded). These data did not differentiate normal weight from overweight participants. Non-response rates were higher than in previously published reports (e.g., Demeter et al., 2008; 2011), with a mean of 5.1% (*SD* = 7.7%) and 6.3% (*SD* = 8.6%) in the SAT and dSAT blocks for signal-present trials, respectively. Signal-absent trials had generally higher rates of non-response, with an average of 16.3% (*SD* = 16.3%) in the SAT blocks and an average of 14.9% (*SD* = 19.1%) in the dSAT blocks. Thus, it appears even through non-responses, subjects were discriminating between signal-present and signal-absent trials. There were no significant group differences in non-response rates, all $p \geq .10$. We identified two subjects (one normal weight and one overweight) who had non-response rates more than three standard deviations from the mean in the SAT blocks. We were concerned these subjects may not have been performing the task correctly, given that their rate of non-response was more than one third of all trials in the baseline, no distraction condition, and that their proportional hit and false alarm rates were therefore potential misrepresentations of their performance. We thus conducted our analysis of d′ after removing data from these subjects[18].

Weight Group Analysis

[18] Including the participants omitted from the analyses reported here had no qualitative effects on the pattern of results. Including the outliers meant more noise in the data, and as such, some comparisons became less significant with the inclusion of outliers.

The weight group analysis showed overweight/obese participants to have overall lower d′ values[19], however, these differences were not significant in the SAT runs. See Table 4.2 for d′ data. Only in the distractor condition did significant differences emerge between overweight/obese subjects and their normal weight counterparts. This is evidence of increased susceptibility of overweight/obese participants to external distraction in the context of sustained attention, consistent with the hypothesis that overweight/obese individuals would be more vulnerable to external distraction. This is also consistent with the hypothesis that overweight/obese individuals do not exhibit global cognitive deficits, but that cognitive control specifically is vulnerable in this population.

We first examined average performance in the SAT and dSAT conditions, to establish whether there were overall effects of weight group on performance, regardless of signal duration or block. An ANOVA on overall performance collapsed across signal duration and block within each task condition revealed a main effect of group, $F(1, 49) = 5.86$, $p < .02$, $\eta_p^2 = .107$, a main effect of task, $F(1, 49) = 127.20$, $p < .0001$, $\eta_p^2 = .722$, but no significant task by group interaction, $F(1, 49) = 2.15$, $p = .15$, $\eta_p^2 = .042$. Though overweight/obese individuals had numerically lower scores both with and without distraction, the group difference in d′ was significant only in the dSAT condition, $t(49) = 2.47$, $p < .02$, $d = .694$, and not in the SAT condition, $t(49) = 1.37$, $p > .17$, $d = .389$.

Next, we examined the data according to signal duration. Specifically, an ANOVA on d′ values at each signal duration indicated that participants demonstrated worse performance in the dSAT blocks compared with the SAT blocks, and that the shortest signal durations were indeed

[19] We also examined SAT scores (see Demeter et al., 2011), which index performance using hits and false alarms [(hits − false alarms) / (2(hits + false alarms) − (hits + false alarms)^2]. These scores range from −1 to +1, with −1 indicating all responses were misses/false alarms and +1 indicating all responses were hits/correct rejections. These analyses yielded a pattern of results nearly identical to the d′ analyses reported here, so we do not report the SAT score analyses separately.

more challenging than the longer ones. The analysis revealed a main effect of weight group, $F(1, 49) = 6.02$, $p < .02$, $\eta_p^2 = .109$, a main effect of task, $F(1, 49) = 95.47$, $p < .0001$, $\eta_p^2 = .661$, a non-significant task by group interaction, $F(1, 49) = 2.34$, $p = .13$, $\eta_p^2 = .046$, a significant effect of signal duration, $F(2, 98) = 69.25$, $p < .0001$, $\eta_p^2 = .586$, a task by signal duration interaction $F(2, 98) = 15.25$, $p < .0001$, $\eta_p^2 = .237$, and no task by signal duration by group interaction, $F < 1$, $p > .9$.

Within the SAT blocks the data were consistent with the hypothesis that performance on SAT blocks would not differ between normal weight and overweight/obese participants because of the relatively low cognitive control demands in the SAT condition. Specifically, there was a significant effect of signal duration, $F(2, 98) = 9.93$, $p = .0001$, $\eta_p^2 = .168$, but no main effect of group or interaction between group and signal duration, both $p > .14$. Planned comparisons revealed no significant group differences at any signal duration, all $t < 1.7$, all $p > .10$.

Within the dSAT blocks the results confirmed the hypothesis that overweight/obese participants would show worse performance in the dSAT blocks. There was a significant effect of signal duration, $F(2, 98) = 57.82$, $p < .0001$, $\eta_p^2 = .541$, a significant main effect of group, $F(1, 49) = 5.79$, $p < .02$, $\eta_p^2 = .106$, and no group by signal duration interaction $F < 1$, $p > .8$, $\eta_p^2 = .003$. Planned comparisons revealed a significant group difference at the 34ms signal duration, $t(49) = 2.29$, $p < .03$, $d = .647$, at the 50ms duration, $t(49) = 2.02$, $p < .05$, $d = .571$, and at the 150ms signal duration, $t(49) = 2.14$, $p < .04$, $d = .610$. These results were consistent with our hypothesis about group differences, though we had initially expected these differences to be larger in magnitude in the more challenging conditions (shorter signal durations).

Since there was a marginally significant effect of block (i.e., block 1 vs. block 2) in the dSAT blocks only, these data were also examined separately for the two blocks. In the first dSAT block, there was a main effect of signal duration $F(2, 98) = 34.82$, $p < .0001$, $\eta_p^2 = .415$, no signal duration by group interaction $F < 1$, $p > .4$, $\eta_p^2 = .015$, and a main effect of group $F(1, 49) = 7.59$, $p < .01$, $\eta_p^2 = .134$. These results demonstrated that the shorter signal durations were more challenging, and that the overweight/obese participants performed more poorly on the task overall. There was a significant group difference at the shortest signal duration, $t(49) = 2.97$, $p < .01$, $d = .836$, a marginal difference at 50ms, $t(49) = 1.79$, $p < .08$, $d = .506$, and a significant difference at 150ms, $t(49) = 2.16$, $p < .04$, $d = .614$.

In the second dSAT block, there was a main effect of signal duration $F(2, 98) = 27.61$, $p < .0001$, $\eta_p^2 = .360$, but no other main effect or interaction, both $F < 1$, $p > .3$. Thus, unlike the first dSAT block, there was no main effect of group. Planned comparisons revealed no significant group differences, all $t < 1.2$, all, $p > .2$, though overweight/obese participants continued to have numerically lower d′ scores[20]. These results are still consistent with the hypothesis that overweight/obese participants are more vulnerable to external distraction, however this effect was less pronounced in the second dSAT block. This may indicate that overweight/obese participants were disrupted by the introduction of distraction in the first dSAT block (compared with the first SAT block), but were able adjust to the presence of this distraction by the second dSAT block, resulting in less dramatic performance differences compared to their lean peers. See Figure 4.2.

Diet Group Analysis

To analyze the influence of current dieting status on performance, we used responses to

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[20] We also examined criterion *c* as an index of response bias that is unaffected by d′ (Macmillan & Creelman, 1990; Stanislaw & Todorov, 1999). Negative values of *c* indicate a bias toward responding yes, while positive values of *c* indicate a bias toward responding no. In an ANOVA on *c* including group and task (SAT vs. dSAT), we found no main effect of group or task, and no interaction between them, all $F < 1.6$, all $p > .2$. This indicates that the group differences in d′ occurred in the absence of changes in *c*. There were also no dieting-related effects on *c*, all $p > .4$

one item on the MBSRQ which read “I am on a weight loss diet.” Participants rated their agreement with this item on a scale from one to five. We grouped anyone responding three or higher as current dieters, and the others as current non-dieters. This gave us a sample of 15 dieters and 38 non-dieters. We repeated the overall analysis strategy reported above for weight group comparisons, this time using diet groups as the variable of interest. None of the main effects or interactions involving diet group as a factor were significant, all $F < 2.1$, all $p > .15$, and no planned comparisons were significant, all $|t|(51) < 1.9$, all $p > .06$.

Correlational Analyses

Though to this point, BMI and dieting status have been treated as dichotomous variables, these variables can be considered continuous dimensions, and in our previous study of working memory, we found several moderately strong relationships between measures of eating and dieting behaviour and performance. We therefore conducted a similar analysis here. In order to evaluate the degree to which dieting and obesity were related to performance in the dSAT task, correlations were computed between d′ scores and several questionnaire variables of interest.

Overall d′ in the SAT and dSAT runs was correlated with variables hypothesized to best capture obesity and dieting behaviour. BMI and average participant adiposity ratings were used to reflect the degree to which a participant was overweight. Item 57 of the MBSRQ, which asked participants to state on a scale from 1 to 5 how strongly they agree with the statement “I am on a weight loss diet,” was included as an index of current dieting behaviour. Total scores on the Restraint Scale, and the uncontrolled eating, emotional eating, and cognitive restraint subscales of the TFEQ were used, along with the restraint, external eating, and emotional eating subscales of the DEBQ as indices of long-term dieting and eating behaviour. Finally, the overweight preoccupation factor subscale of the MBSRQ was used as an index of how much participants worried about being or becoming overweight. We hypothesized that, as in our study of working memory, measures of adiposity would correlate negatively with performance, as would measures of restraint, dieting, and overweight preoccupation. We included the TFEQ and DEBQ subscales unrelated to restraint in an exploratory factor, and thus applied a Bonferroni correction to these comparisons.

As predicted, objective measures of overweight/obesity correlated with d′. However, unlike our previous work in the working memory domain, there were no significant correlations with weight-related worry, dieting, and restraint. In particular, BMI was correlated with SAT d′, $r = -.36$, as was the average adiposity rating variable, $r = -.34$, both $p < .02$. Both BMI and average adiposity rating were also correlated with dSAT d′, $r = -.36$ and $r = -.33$, respectively, both $p < .02$. No other correlations were significant.

Discussion

The results from Experiment 1 showed that overweight/obese individuals performed more poorly than their lean peers in a sustained attention task, but only in the distractor condition were these group differences significant. This indicates a specific vulnerability in controlling distraction. This vulnerability points to a deficit restricted to the control processes involved in this type of operation, rather than a global attention or cognitive deficit. Unlike previous investigations, there was no indication that either current dieting status or restrained eating behavior was related to sustained attention performance, with or without distraction.

The participants in Experiment 1 completed the SAT and dSAT at the end of a long experimental session, during which they had already completed more than one and a half hours of cognitively demanding tasks and questionnaires. This raises the question of whether the deficits in controlling attention under conditions of distraction documented here occurred as a result of a cognitive fatigue effect, or whether these deficits would be apparent regardless of how much cognitive effort had been expended immediately prior to task performance. We conducted Experiment 2 in order to assess the replicability of the effects in Experiment 1, and to assess the question of whether deficits in controlling sustained attention under conditions of distraction are present regardless of prior cognitive engagement.

Experiment 2

Method

Participants

Fifty young adults between the ages of 18 and 25 participated in the experiment. One participant was excluded because experimenter error resulted in missing data, and a second subject was excluded for a diagnosis of depression and bipolar disorder. This left a total sample of 48 participants, with 24 normal weight and 24 overweight participants. Two further subjects were removed from analysis after examination of the data. One subject had high levels of non-response trials (in some runs as high as 86%) more than three standard deviations from the mean in three of four runs, leaving only one run of SAT data for analysis. This subject was therefore excluded from all analyses below. A second subject had high levels of non-response data more than three standard deviations from the mean in two of four runs, as well as strongly negative d′ values (between -1 and -2) on more than one trial type. This subject was also excluded from all analyses below. This left a final sample of 23 subjects per group. We identified several other outliers who had non-response rates more than three standard deviations from the group mean in at least one run. We present non-response analyses including data from these affected participants, and then d′ analyses excluding the affected runs for the affected subjects[21]. All included subjects were healthy with no reported medical diagnosis or medication that would influence their weight. See Table 4.1 for participant characteristics.

Task

The task was programmed in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA), and was the full version of a task employed by Demeter and colleagues (2013). The timing and signal parameters were identical to Experiment 1.

Procedure

After completing informed consent and a demographics survey, participants completed the practice as in Experiment 1. Each participant then completed two 12-minute runs of the SAT condition, and two 8-minute runs of the dSAT condition. Each dSAT run was identical in form to the run described in Experiment 1—a 2-minute block of SAT, two 2-minute blocks of dSAT, a 2-minute block of SAT. The SAT runs consisted of six, 2-minute blocks of the SAT. Participants completed the SAT and dSAT runs in an alternating order, with the first run counterbalanced across participants. That is, half of the participants in each group completed the SAT, dSAT, SAT, dSAT order, and half the reverse order.

Participants then completed the same battery of questionnaire measures used in Experiment 1. Following completion of the questionnaire battery, participants' height and weight were measured. The inter-rater reliability of the visual adiposity rating measure was .79 in this sample.

It was hypothesized that overweight/obese individuals would perform more poorly on the dSAT runs compared with their lean peers. It was also hypothesized that performance in the SAT

[21] Including the affected runs did not substantively alter the pattern of results reported here for weight group analyses. Inclusion of affected runs resulted in the significant dieting effects reported below failing to achieve significance.

runs would not differ between groups. Finally, we expected that the effects would be strongest under the most challenging task conditions. We did not expect dieters to perform more poorly in any condition, given the lack of any significant effects in Experiment 1.

Results

Non-Response Data

This time, non-response rates were more similar to those from previous reports, and there were no group differences in the SAT runs. Overall levels of non-response were very low in the pure SAT runs, with means of 1.0% (*SD* = 3.7%) and 0.9% (*SD* = 2.4%) in runs one and two on signal-present trials, and means of 0.9% (*SD* = 1.9%) and 1.1% (*SD* = 2.6%) in runs one and two on signal-absent trials. There were no significant group differences in non-response rates in these runs, all $t(44) < 1.7$, all $p > .10$.

Similarly, levels of non-response were low in the SAT blocks of the dSAT runs, with no group differences. Non-response means were 2.3% (*SD* = 4.4%) and 1.7% (*SD* = 5.6%) in runs one and two on signal-present trials, and 6.3% (*SD* = 9.5%) and 3.9% (*SD* = 7.0%) in runs one and two on signal-absent trials. There were no significant group differences in non-response rates in these blocks, all $t(44) < 1.6$, all $p > .12$.

Finally, in the dSAT blocks of the dSAT runs, there were generally higher levels of trials without response, and here there were group differences, with overweight/obese individuals not responding to more trials than normal weight individuals. To the extent that failing to respond can be considered an index of poor task performance, these data indicate that overweight/obese individuals performed more poorly, but only in the distractor condition. Mean non-response rates were 3.3% (*SD* = 4.9%) and 3.2% (*SD* = 8.3%) in runs one and two on signal-present trials, and 8.3% (*SD* = 10.6%) and 5.6% (*SD* = 10.0%) in runs one and two on signal-absent trials. There was one marginal group difference between overweight (*M* = 5.43%, *SE* = 2.34%) and normal weight subjects (*M* = 0.98%, *SE* = 0.45%) in non-responses on signal-present trials in run two, $t(44) = -1.86$, $p = .07$, $d = -.662$, and one significant group difference between overweight (*M* = 8.57%, *SE* = 2.71%) and normal weight participants (*M* = 2.61%, *SE* = 0.83%) in non-responses on signal-absent trials in run two, $t(44) = -2.10$, $p < .05$, $d = -.702$.

Weight Group Analyses

As outlined previously, we identified four subjects who had outlying levels of non-response data in at least one run. We excluded one subject from the first SAT run, two subjects from the second SAT run, one subject from the first dSAT run, and one subject from the second dSAT run. The results of these analyses showed no significant differences between groups, although the overall pattern of performance was highly similar to the pattern of performance in Experiment 1. See Figures 4.3 and 4.4.

Data from the SAT runs indicated no group differences in performance, consistent with our hypothesis that the relatively low control demands of the baseline condition would not be challenging enough to elicit a decrement in performance from the overweight/obese group. See Table 4.3 for d′ data. An ANOVA on overall d′ scores in the two dSAT runs showed a marginal interaction between run and task, $F(1, 42) = 2.80$, $p = .10$, $\eta_p^2 = .063$, and a run by task by group interaction that trended, $F(1, 42) = 2.17$, $p < .15$, $\eta_p^2 = .049$, so we examine each run individually as well as overall. There was no such effect of run in the SAT runs, $F(1, 41) < 1$, $p > .8$, so we collapsed performance across the two runs for subsequent analyses. Additional analysis of SAT runs on overall d′ by block revealed no main effect of group, $F < 1.08$, $p > .3$, and no other effects, *F*s < 1.5, *p*s ≥ .2. Planned comparisons revealed that there were no significant group differences, all $t < 1.4$, all $p > .17$.

Examining overall SAT performance by signal duration revealed no main effect of group, $F < 1$, $p > .4$, a main effect of signal duration, $F(2, 88) = 61.87$, $p < .0001$, $\eta_p^2 = .584$, and an interaction between signal duration and group, $F(2, 88) = 4.47$, $p < .02$, $\eta_p^2 = .092$. The main effect of signal duration reflects the expected pattern of poorer performance on shorter signal durations. Planned comparisons revealed no significant group differences at any signal duration, all $t(44) \leq 1.5$, all $p > .15$. Finally, a t-test on overall SAT d′ scores revealed no group difference, $t(45) < 1$, $p > .3$, $d = .270$, though overweight subjects did have numerically lower scores. Again, these analyses highlight that although overweight participants may generally have performed more poorly, there were no statistically significant group differences in the SAT condition. See Figure 4.5.

The dSAT runs were analyzed separately initially due to marginal interactions of run, task, and group, however, the pattern of results for both runs was highly similar: ANOVAs including task, group, and signal duration revealed no main effects of group, Fs < 1.2, ps > .25, main effects of task, Fs > 52, ps < .0001, $\eta_p^2 > .549$, and signal duration, Fs > 54, ps < .0001, $\eta_p^2 > .558$, an interaction between task and signal duration, Fs > 8, ps < .001, $\eta_p^2 > .167$, but no other significant interactions, all $F < 1.6$, all $p > .2$. The main effect of signal duration reflected improving d′ scores from shortest to longest signals, and the interaction between signal duration and task reflects that this increase was more dramatic for the distractor condition. Planned comparisons revealed that there were no significant differences between groups at any signal duration, all $|t| < 1.2$, all $p > .2$. Examining individual dSAT blocks within each run yielded no significant main effects or interactions except the usual main effect of signal duration (Fs > 22, ps < .0001), but no other significant main effects, interactions, or planned comparisons, all $p > .17$.

Overall then, although overweight/obese individuals consistently had lower mean d′ and although this seemed to be especially true in the distraction condition (see Figures 4.3 and 4.4), the effects did not reach statistical significance. The pattern of results was similar to that of Experiment 1, but the magnitude of the effects was not as great[22].

Diet Groups Analysis

Although we did not see effects of dieting in our analysis of Experiment 1 data, we examined dieting again for consistency. Participants were therefore assigned to current dieter and current non-dieter groups using the same procedure as in Experiment 1, resulting in a sample of 15 dieters and 31 non-dieters. There were no consistent results indicating dieters to be impaired on performance of the dSAT, similar to our results from Experiment 1, however, there were indications that dieting was related to performance in the baseline, SAT condition.

The SAT analyses revealed some diet group differences, in contrast with our own previous data and our hypothesis for Experiment 2 that we would not find effects of dieting. An ANOVA on overall d′ by block combined across the two SAT runs revealed no significant effects, *F*s < 3.2, *p*s > .08. Planned comparisons revealed that dieters performed more poorly than non-dieters in block four, $t(44) = -2.59$, $p = .01$, $d = -.815$, but no other significant differences, all $|t| < 1.6$, all $p > .13$.

Examining overall SAT performance by signal duration revealed a main effect of diet group, $F(1, 44) = 3.99$, $p = .05$, $\eta_p^2 = .083$, a main effect of signal duration, $F(2, 88) = 58.98$, p <

[22] We also examined criterion *c*, finding that in an ANOVA with group and task (overall SAT run performance vs. overall performance from the dSAT blocks of the dSAT runs), there was a main effect of group that failed to reach significance, $F(1, 44) = 3.38$, $p = .07$, $\eta_p^2 = .071$, no effect of task, and no interaction, both $p > .10$. T-tests revealed that the marginal main effect of group was due to a significant group difference only in the SAT runs, where overweight participants had higher mean *c* (0.31, *SE* = 0.04) than their lean peers ($M = 0.18$, $SE = 0.04$), $t(44) = -2.49$, $p < .02$, $d = -.736$, indicating that overweight participants had more bias toward “no” responses. There were otherwise no differences in *c*, despite the pattern of lower d′ values. There were no dieting related differences in *c*, all $p > .19$.

.0001, η_p^2 = .573, and a non-significant interaction between signal duration and diet group, $F(2, 88) = 2.69$, $p = .07$, η_p^2 = .058. The main effect of signal duration reflected poorer performance at shorter signal durations. Planned comparisons revealed that dieters performed marginally more poorly than non-dieters at 34 ms, t(44) = -1.89, p = .07, d = -.595, and significantly more poorly at 50 ms, t(44) = -2.45, p < .02, d = -.772, but not at 150 ms, $t(44) = -1.08$, $p > .28$, d = -.344.

The distraction condition data yielded different results from the baseline SAT condition that were more in line with our predictions—no consistent effects of dieting on task performance. An ANOVA on overall d′ in the two dSAT runs showed a marginal interaction between run and task, $F(1, 42) = 3.40$, $p = .07$, η_p^2 = .075, so we initially separated the two runs in our analysis. However, the pattern of results turned out to be nearly identical: no main effect of diet group, Fs < 1, ps > .8, a main effect of task, Fs > 41, ps < .0001, η_p^2 > .490, and signal duration, Fs > 50, ps < .0001, η_p^2 > .540 and interactions between task and signal duration, Fs > 9, ps < .001, η_p^2 > .180, and task by signal duration by diet group interactions that failed to reach significance, Fs < 2.7, ps > .07. Planned comparisons revealed no significant differences between diet groups at any signal duration, all t < 1.3, all p > .2.

A final analysis on overall data from the SAT runs and dSAT blocks of the dSAT runs showed a main effect of task, $F(1, 44) = 114.93$, $p < .0001$, η_p^2 = .723, all other F < 1.5, p > .2. T-tests revealed worse performance for the dieting group in the SAT runs, $t(44)$ = -.2.15, p < .04, d = -.678, but not in dSAT performance, $t(44)$ = -.28, p > .7, d = -.089. Thus, dieters appeared to perform more poorly in the baseline SAT condition, but not the more challenging distractor dSAT condition.

Correlation Analyses

As in Experiment 1, correlations were computed between questionnaire variables of interest and overall d′ scores in both SAT and dSAT runs. Unlike Experiment 1, there were significant correlations between dieting (r = -.34, p < .03), Restraint scores, (r = -.33, p < .03), overweight preoccupation, (r = -.33, p < .03), TFEQ cognitive restraint, (r = -.44, p < .01), DEBQ restraint, (r = -.36, p < .02), and overall d′ in the SAT runs. The Restraint, TFEQ cognitive restraint, and DEBQ restraint scales all measure similar constructs related to restrained eating, so it seems that dieting, restraint eating, and overweight preoccupation were each related to performance in the SAT. There were no significant correlations between any variable and dSAT d′ scores, all $|r|$ < .23, all p > .10.

Discussion

The results of Experiment 2 showed no reliable group differences between normal weight and overweight/obese individuals in the SAT or its distractor condition, unlike the results of Experiment 1. However, it was consistently true that overweight participants were outperformed by their normal weight peers, even though these numerical differences failed to reach significance. Indeed, the overall pattern of results was quite similar to that of Experiment 1[23], though muted in appearance.

The results of Experiments 1 and 2 considered together are consistent with our hypothesis regarding performance of overweight/obese individuals in sustained attention with distraction. However, these tasks did not contain any food-related distraction, so we have not yet been able to assess our hypothesis that overweight/obese and dieting individuals would show compromised

[23] We statistically tested the performance of participants combined across the two experiments. An ANOVA with group, task, and experiment as independent variables, and overall SAT d′ and overall dSAT d′ as dependent variables revealed only a main effect of group, $F(1, 93) = 5.74$, $p < .02$, $\eta_p^2 = .058$, and a main effect of task, $F(1, 93) = 260.76$, $p < .0001$, $\eta_p^2 = .737$. There were no other significant effects, all $F < 1.4$, all $p > .2$. This is consistent with the two experiments having similar patterns of performance.

sustained attentional control when confronted with food-related challenges to attention. We therefore conducted Experiment 3 to evaluate this hypothesis.

A previous pilot study from our lab (Ossher et al., unpublished data) using the Continuous Temporal Expectancy Task (CTET; O'Connell et al., 2009) as a sustained attention task explored the effect of food-related distraction. We included an audiovisual distractor condition modeled after Berry and colleagues (Berry et al., 2013) in which each 4-minute run of the CTET was presented with a 4-minute distracting video composed of eight 30-second clips, presented on an adjacent laptop. Briefly, this preliminary study revealed overall significantly worse performance in the overweight/obese group, but this was true in the baseline condition as well as the distraction condition, and was unaffected by the content of the distractor videos. Those distraction videos were not well-matched across the food and food-neutral conditions, with the food-neutral videos reported to be more interesting by participants, and the CTET itself is a fundamentally different kind of sustained attention task than the dSAT, relying on timing perception and requiring only occasional response.

In Experiment 3, we return to our use of modified versions of the SAT and dSAT in order to maintain consistency with Experiments 1 and 2. We carefully matched our distractors in Experiment 3, in order to allow a systematic comparison of the food-related and food-neutral distraction conditions. Finally, we draw on the attentional bias literature that suggests we should be able to detect some effect of food-related attentional capture specific to some facet of obesity and/or dieting behaviour. As outlined above, previous studies have identified selective attentional bias toward food cues in a variety of populations known to have eating-related issues, including eating disorders (Faunce, 2002; Mobbs et al., 2011; Placanica et al, 2002), restrained and external eating and dieting (Brignell et al., 2009; Cooper & Fairburn, 1992; Francis, Stewart

& Hounsell, 1997; Hou et al., 2011; Overduin et al., 1995), food craving and hunger (Gearhardt et al., 2012; Smeets et al., 2009; Tapper et al., 2010), and obesity (Castellanos et al., 2009; Loeber et al., 2011; Mobbs et al., 2011; Nijs et al., 2010; Nummenmaa et al., 2011; Yokum et al., 2011). One intriguing finding from a previous study with regard to our distraction manipulation is that in a visual search paradigm, obese individuals showed increased processing of food distractors when searching for non-food items (Smeets et al., 2009). Our own assessment of distraction from task-intrinsic food-related material in working memory, and food-neutral material in sustained attention, suggest that there may be some deficit in controlling responses to distraction in obesity. Though we have evidence that this deficit in handling challenges to attention is food-specific in working memory, Experiment 3 is our first opportunity to evaluate the comparable hypothesis in sustained attention.

Using two tasks, we present food and non-food distraction during the course of performing a modified version of the SAT. In one case (the video SAT), we present a video manipulation as described above in the CTET experiment. This allows us to assess the impact of irrelevant, task-extrinsic, peripherally presented distraction, and the influence of food versus non-food content. In the second case (the image SAT), we present the SAT with the usual strobe manipulation, but change the content of the flashing screen to be food or non-food images. This allows us to assess the impact of irrelevant, centrally presented distraction, and the influence of food versus non-food content.

Experiment 3

Method

Participants

Seventy-one adults between the ages of 18 and 22 participated in the experiment and were compensated for their time. Three participants were excluded due to computer error causing missing data or failure to play the video distractors correctly. Two participants were excluded for current medication and medical diagnoses known to affect weight, one participant was excluded for current depression and medication use, and a final participant was excluded for a recent concussion and history of learning disorder. These participants were replaced to yield a sample of 64 in total.

Weight groups (normal weight, overweight/obese) were defined by BMI cut-offs, as before. This yielded a sample of 32 normal weight and 32 overweight participants, allowing the counterbalancing of task order and task content across participants in each group. All included subjects were healthy with no reported medical diagnosis or medication that would influence their weight. See Table 4.4 for participant characteristics.

Tasks

Video SAT. The task was programmed in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). The video SAT consisted of two runs, each with two blocks of a modified SAT with no distraction, and two blocks of a modified dSAT, organized in the pattern SAT, dSAT, dSAT, SAT. In each block of the SAT or dSAT, 3.5mm^2 signals (grey squares on a silver background) appeared in one of 3 locations on the computer screen. The three locations were centered, with the first location occurring at 30% of the vertical height of the screen, the second at 50% and the third at 70%. The signals appeared for one of three durations: 34, 50, or 150ms. The 34ms signals were twice as probably as the 50 and 150ms signals. There was a 50% probability of a signal occurring on any given trial.

Each trial began with a 1000 ms monitoring period consisting of a blank silver screen. Following the monitoring period, a signal appeared for one of the durations specified above, followed by an additional 1500 ms of blank silver screen before the next trial began. Participants were given 1000 ms from the end of the signal to respond, and were instructed to press the space bar whenever they detected a signal on screen, and that they would only have a very short time to do so. There was no auditory feedback presented for correct or incorrect responses or non-responses. These task parameters applied to all blocks of the task. In each block, as many trials as possible were presented in two minutes, for a total run length of eight minutes.

The distraction condition (dSAT) had identical task parameters. The distraction component was introduced using video clips playing on a laptop adjacent to the main computer used to present the E-prime task. The videos comprised eight 30-second video clips (for a total of four minutes of distraction). The video distraction was modeled on a previous sustained attention task using video distractors (Berry et al., 2013), and a previous experiment from our own lab (Ossher et al., unpublished data) using the CTET (O'Connell et al., 2009). We created two versions of the video distraction. One version consisted of food-related video clips, and the other food-neutral clips. The clips were downloaded from YouTube, and edited to be 30 seconds long. Each food-related clip showed a TV personality from the Cooking Channel or Food Network preparing and describing a dish. The food-neutral clips each showed a TV personality from Home & Garden Television preparing and describing a home improvement project. We selected these two kinds of videos because they were already closely matched in format, production value, musical content, and overall style. We initially created a corpus of 22 food videos and 26 non-food videos, and collected ratings from four research assistants to identify the 20 videos in each category that were best matched to each other. We then collected data from 16 pilot subjects (eight normal weight and eight overweight/obese), who viewed each video and rated each on how colourful it was, how much sound there was, how much it captured their attention, how interesting they found it, how much music they noticed, and whether it stood out as different than the others on a scale from one to ten. This last question ended up being problematic because subjects were not sure how to interpret it, and ratings were unusually distributed, so we did not consider it further. Eight videos were then selected from each category such that there were no significant differences between food and non-food videos on any dimension, all $p > .10$. The videos were also matched so that there were no differences between weight groups on overall ratings of any dimension, all $p > .25$.

We created four randomized orders of the clips with the condition that a clip did not appear in the same place in the order (e.g., third out of eight) in more than one order. There were thus four orders of the food videos, creating four 4-minute distraction videos comprising eight 30-second distractor clips, and the same for the non-food videos. Sound levels were equated across all clips. All editing was done using Movie Maker (Microsoft, Seattle, WA) and Audacity (http://audacity.sourceforge.net/), and videos were displayed for participants using VLC media player (VideoLAN Organization). Videos were appended with 2-minute clips of silver screen with no sound at the beginning and end, to create a single, 8-minute long video that was displayed on the adjacent laptop and started at the same time that the E-prime script initiated stimulus presentation. The research assistant administering the testing session pressed the buttons to trigger both presentations simultaneously. Subjects wore headphones and completed the task in a soundproofed testing room. The four food and four non-food video versions were counterbalanced across participants such that each version occurred equally often. Run order was also counterbalanced across participants such that half of the subjects completed the food run first, and half completed the non-food run first. Since false alarms were almost entirely absent, we decided that d′ would not be the best measure to use, and performance in this task was measured using hits, and hits – false alarms.

Before starting the task, participants completed a brief practice program, with 30 seconds of practice at the SAT. There was no video distraction during the practice. Participants were instructed that sometimes there would be things playing on the laptop screen, just like in real life where there can sometimes be TVs or radios playing in the background. They were also instructed that the main task was to detect when a signal appeared on the main screen.

Image SAT. The task was programmed in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). The image SAT consisted of one run with two blocks of a modified SAT with no distraction, and two blocks of a modified dSAT, organized in the pattern SAT, dSAT, dSAT, SAT. In each block of the SAT or dSAT, 3.5mm^2 signals (grey squares on a silver background) appeared in one of 3 locations on the computer screen. The three locations were centered, with the first location occurring at 30% of the vertical height of the screen, the second at 50% and the third at 70%. The signals appeared for one of three durations: 34, 50, or 150ms. The 34ms signals were twice as probably as the 50 and 150ms signals. There was a 50% probability of a signal occurring on any given trial.

Each trial began with a 1000, 2000, or 3000 ms blank silver screen monitoring period. Each monitoring period was equally probable on any given trial. Following the monitoring period, a signal appeared for one of the durations specified above. Ten screen changes (2500 ms) after a signal (or non-signal) occurred, participants were cued to respond by a short buzzer sound (approximately 300 ms in duration). Participants were given 1500 ms to respond, and received auditory feedback in the form of a short ringing sound if they responded correctly (also approximately 300 ms in duration). There was no feedback for incorrect responses or non-responses. Thus, participants were meant to respond to all trials, allowing the assessment of hits, false alarms, misses and correct rejections. Performance in this task was measured using d′.

In the distractor condition, the same task parameters applied, but the screen alternated between a solid silver background and an image background at 2 Hz throughout each trial, providing a highly salient perceptual distractor difficult to ignore. The images were varied in their composition, so three square areas of the screen (each 25 mm^2) remained silver throughout the strobing, indicating to the participants the three locations in which a signal might appear. The signals appeared within these silver portions of the screen, so the signal-to-background contrast was consistent with the no-distraction condition.

The images used in the distractor condition were either images of food or images of birds in the wild. We selected these categories of items after data from a separate pilot experiment indicated that they performed consistently as stimuli. Images were randomly drawn without replacement on each trial for each subject, and the same image never appeared twice within a testing session.

Each block of the task consisted of 72 trials such that each monitoring period, signal location, and signal duration were fully crossed. The order of bird and food distraction blocks was counterbalanced across subjects such that half of the participants completed each order (e.g., food-bird or bird-food).

Before starting the task, participants completed a practice program with 16 trials of no-distraction task and 16 trials with distraction, half of each category. The bird and food distraction trials were blocked and presented in the same order as the main task (e.g., if a participant was assigned to the food-bird counterbalance order, they did practice with food trials first, then bird trials, for consistency. The participants were given the opportunity to repeat the basic, no distraction practice and/or the image distraction practice if they wanted to.

Procedure

After completing informed consent and a demographics survey, participants began with either the video or image SAT. The order of tasks was counterbalanced, and the order of food and non-food blocks within each task was fully crossed. Participants had a short break between tasks, along with the practice for the second task. After completing the tasks, participants were given a questionnaire assessing how distracted they felt during the video task, adapted from a questionnaire used by Berry and colleagues (2013). Then, participants completed a multiple-choice test about the content of the distractor videos, consisting of 16 questions per video type, with two questions about each video clip.

Participants then completed a battery of questionnaire measures, including the Dutch Eating Behaviour Questionnaire (DEBQ; van Strien, Frijters, Bergers, & Defares, 1986), the Restraint Scale (Herman & Polivy, 1975; 1980), and the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) as assessments of eating behaviours and attitudes; personal and family weight history questions to assess individual and familial weight history; the Multi-Dimensional Body-Self Relations Questionnaire (MBSRQ; Brown, Cash, & Mikulka, 1990; Cash, 2000) as measures of body image; questions about hunger levels during the experiment; the Weight Locus of Control scale (WLOC; Saltzer, 1982); the Yale Food Addiction Scale (YFAS; Gearhardt, Corbin, & Brownell, 2009) as an additional measure of food behaviour and attitudes; the Food Craving Inventory (FCI-II; White & Grilo, 2005; White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002); the Barratt Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995) as a measure of behavioural impulsivity; and the Power of Food Scale

(PFS; Lowe et al., 2009; Cappelleri et al., 2009) as additional measures of food behaviour and attitudes. Finally, they completed the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003).

Following completion of the questionnaire battery, participants' height and weight were measured. We also included the visual adiposity rating measure, as before. The inter-rater reliability of this measure was .83 in this sample. Additionally, we measured waist and hip circumference, to calculate waist to hip ratio. Then, participants completed a post-experimental questionnaire, including questions about their strategy use and impressions of the experiment.

Results

Video SAT Results

Weight group analyses. We first examined hits minus false alarms for performance in the food distraction and no distraction blocks, and the non-food distraction and no distraction blocks. See Table 4.5 for Video SAT performance data. Results were not consistent with our hypotheses. Specifically, there were no main effects or interactions with weight group, as overweight/obese individuals did not perform more poorly. Food appeared to be the more effective distractor content, but this was true for both groups of participants. In particular, an ANOVA including group (normal weight vs. overweight), distraction type (food vs. non-food), and task condition (distraction vs. no distraction) yielded no main effect of group, $F < 1$, $p > .9$, $\eta_p^2 < .001$, no main effect of distraction type, $F(1, 62) = 1.84$, $p = .18$, $\eta_p^2 = .029$, no interaction between distraction type and group, $F(1, 62) = 1.90$, $p = .17$, $\eta_p^2 = .030$, a main effect of condition, $F(1, 62) = 5.08$, $p < .03$, $\eta_p^2 = .076$, no interaction between condition and group, $F(1, 62) = 1.30$, $p > .25$, $\eta_p^2 = .020$, no interaction between distraction type and condition, $F(1, 62) = 2.63$, $p > .10$, $\eta_p^2 = .041$, and no three way interaction, $F < 1$, $p > .4$, $\eta_p^2 = .009$. The main effect of condition was due to the distraction blocks (*M* = 91.9%, *SE* = 1.3%) having significantly lower accuracy than the no distraction blocks (*M* = 93.5%, *SE* = 0.96%). Planned comparisons revealed no significant group differences in either the food or non-food blocks, either with or without distraction, all $|t| < 1$, all $p > .4$.

Examining the no distraction data, split by first versus fourth block revealed no main effect of group, $F < 1$, $p > .5$, $\eta_p^2 = .005$, a main effect of category, $F(1, 62) = 6.38$, $p < .02$, $\eta_p^2 = .093$, a main effect of block, $F(1, 62) = 4.67$, $p < .04$, $\eta_p^2 = .070$, but no other significant effects, all $F < 2.2$, all $p > .15$. The main effect of block was due to lower accuracy in the fourth block (*M* = 92.6%, *SE* = 1.2%) than in the first block (*M* = 94.1%, *SE* = 1.0%). The main effect of category was due to lower accuracy in the non-food blocks (*M* = 92.5%, *SE* = 1.2%) than in the food blocks, (*M* = 94.2%, *SE* = 1.0%). Planned comparisons revealed no significant differences between groups, all $|t| < 1.2$, all $p > .25$.

Examining the distraction data, split by second versus third block revealed only a main effect of block, $F(1, 62) = 5.82$, $p < .02$, $\eta_p^2 = .086$, with no other significant main effects or interactions, all $F < 1.7$, all $p > .19$. The main effect of block was due to lower accuracy in block three (*M* = 90.8%, *SE* = 1.6%) than in block two (*M* = 92.9%, *SE* = 1.3%). Note that in both distraction and non-distraction blocks, there was a significant decline in accuracy over time, consistent with a vigilance decrement. Planned comparisons revealed no significant group differences, all $|t| < 1$, all $p > .3$.

Examining the food run hit data more closely, an ANOVA including group, task condition, and signal duration showed only a main effect of distraction, $F(1, 62) = 6.71$, $p < .02$, $\eta_p^2 = .098$, and a main effect of signal duration, $F(2, 124) = 35.31$, $p < .0001$, $\eta_p^2 = .363$. The main effect of distraction reflects the same pattern reported above, with higher accuracy under no distraction conditions (*M* = 94.6%, *SE* = 0.82%) than under distraction conditions (*M* = 92.3%, *SE* = 1.3%). The main effect of signal duration reflected increasing accuracy from 34 ms signals (*M* = 90.5%, *SE* = 1.4%) to 50 ms signals (*M* = 95.0%, *SE* = 1.1%) to 150 ms signals (*M* = 97.2%, *SE* = 0.9%). Planned comparisons revealed no significant group differences, all $|t| < 1.5$, all $p > .14$.

Repeating this analysis on the non-food blocks revealed only a main effect of signal duration, $F(2, 124) = 28.01$, $p < .0001$, $\eta_p^2 = .311$, with no other main effects or interactions, all $F < 1$, all $p > .3$. The main effect of signal duration again reflected increasing accuracy from 34 ms signals (*M* = 90.0%, *SE* = 1.5%) to 50 ms signals (*M* = 93.5%, *SE* = 1.4%) to 150 ms signals (*M* = 97.1%, *SE* = 0.8%). Planned comparisons revealed no significant group differences, all $|t| < 1.1$, all $p > .2$

Overall then, the results from the video SAT indicate that food was a more effective distractor than non-food content, but this was true for everyone—there was no differential effect of one type of distraction in either group. The video distraction was moderately effective overall, with most (but not all) comparisons detecting a significant effect of distraction. The signal duration manipulation was also effective, with the predicted ordering of signal durations in terms of accuracy. This task did not support our hypothesis that overweight/obese individuals would be more affected by food distraction than their lean peers, and there was no evidence that they were uniquely affected more by the food than non-food distraction.

Diet group analyses. Though our previous sustained attention experiments had not yielded effects of dieting, the previous sustained attention experiment had not included any food-related stimuli. In light of documented attentional biases in restrained eaters, people with cravings, and people who were hungry (e.g., Nijs et al, 2010; Overduin et al., 1995; Smeets et al., 2009; Tapper et al., 2010), we hypothesized that in the presence of food-related distraction, we might elicit a detrimental effect on performance in our dieting group. To analyze the influence of current dieting status on performance, we used responses to one item on the MBSRQ which read "I am on a weight loss diet." Participants rated their agreement with this item on a scale from one to five. We grouped anyone responding three or higher as current dieters, and the others as current non-dieters. This gave us a sample of 22 dieters and 42 non-dieters (41 in the image SAT data because of the excluded subject; see image SAT results below).

Results were not consistent with our dieting hypothesis: there was no indication that dieters performed more poorly, regardless of the distractor content. We first examined hits minus false alarms for performance in the food distraction and no distraction blocks, and the non-food distraction and no distraction blocks. An ANOVA on overall hits minus false alarms including diet group (dieter vs. non-dieter), distraction type (food vs. non-food), and task condition (distraction vs. no distraction) yielded only a main effect of distraction condition, $F(1, 62) = 4.97$, $p < .03$, $\eta_p^2 = .074$. There were no other main effects or interactions, all $F < 2.5$, all $p > .12$. As previously reported in the weight group analysis, the main effect of distraction reflected lower accuracy in the distraction condition compared with the no distraction condition. Planned comparisons revealed no significant group differences in either the food or non-food blocks, either with or without distraction, all $|t| < 1$, all $p > .4$.

Examining the no distraction data, split by first versus fourth block revealed no main effect of group, $F < 1$, $p > .6$, $\eta_p^2 = .004$, a main effect of category, $F(1, 62) = 7.05$, $p < .01$, $\eta_p^2 = .102$, a main effect of block, $F(1, 62) = 5.51$, $p < .03$, $\eta_p^2 = .082$, but no other significant effects, all $F < 1$, all $p > .3$. As previously indicated, the main effect of block was due to lower accuracy in the fourth block than in the first block and the main effect of category was due to lower accuracy in the non-food blocks than in the food blocks. Planned comparisons revealed no significant differences between groups, all $|t| < 1$, all $p > .4$.

Examining the distraction data, split by second versus third block revealed a main effect of block, $F(1, 62) = 4.70$, $p < .04$, $\eta_p^2 = .070$, and a three way category, by block by diet status interaction, $F(1, 62) = 3.88$, $p = .05$, $\eta_p^2 = .059$, with no other significant main effects or interactions, all $F < 1$, all $p > .4$. As previously reported, the main effect of block was due to lower accuracy in block than in block two. Planned comparisons revealed no significant diet group differences, all $|t| < 1.5$, all $p > .14$. The interaction likely arose because dieters had numerically lower accuracy in block two of the non-food run, ($M = 90.2$ vs. 94.2%, $SE = 2.9$ vs. 1.3% for dieters and non-dieters, respectively), but had numerically higher accuracy in other blocks.

Examining the food run hit data more closely, an ANOVA including group, task condition, and signal duration showed only a main effect of distraction, $F(1, 62) = 6.06$, $p < .02$, $\eta_p^2 = .089$, and a main effect of signal duration, $F(2, 124) = 33.46$, $p < .0001$, $\eta_p^2 = .350$, all other $F < 1$, all other $p > .2$. The main effect of distraction reflects the same pattern reported above, with higher accuracy under no distraction conditions than under distraction conditions. The main effect of signal duration reflected increasing accuracy from 34 ms signals to 150 ms signals, as reported above. Planned comparisons revealed no significant differences, all $|t| < 1$, all $p > .3$.

Repeating this analysis on the non-food blocks revealed only a main effect of signal duration, $F(2, 124) = 31.07$, $p < .0001$, $\eta_p^2 = .334$, with no other main effects or interactions, all $F < 1$, all $p > .10$. The main effect of signal duration again reflected increasing accuracy from 34 ms signals to 150 ms signals as previously reported. Planned comparisons revealed no significant diet group differences, all $|t| < 1.2$, all $p > .2$

Correlational analyses. BMI and dieting status can be considered continuous dimensions, and in our previous dSAT study, BMI was moderately well-correlated with task performance metrics. We therefore conducted similar correlational analyses using the hits – false alarms from the food and non-food distraction, and the no distraction blocks. In order to evaluate the degree to which dieting and obesity were related to performance, correlations were computed with several questionnaire variables of interest hypothesized to best capture the dimensions of obesity and dieting behaviour.

BMI, waist to hip ratio, and average participant adiposity ratings were used to reflect the degree to which a participant was overweight. Additionally, item 57 of the MBSRQ was included as an index of current dieting behaviour. Total scores on the Restraint Scale, and the uncontrolled eating, emotional eating, and cognitive restraint subscales of the TFEQ were used, along with the restraint, external eating, and emotional eating subscales of the DEBQ as indices of long-term dieting and eating behaviour. The overweight preoccupation factor subscale of the MBSRQ was used as an index of how much participants worried about being or becoming overweight. YFAS symptom count was used as a metric of addictive behaviour with food, and FCI total scores were included as an index of craving. We hypothesized that BMI and adiposity ratings would be negatively related to performance in the food condition. We also hypothesized that dieting, dietary restraint, and overweight preoccupation would be correlated with food condition performance, based on previous results. We were also able to assess the relationship between food addiction symptoms and food craving metrics (YFAS, FCI and PFS scores), and hypothesized that these variables would also be negatively correlated with food condition performance. Finally, we included the external, emotional, and uncontrolled eating subscales of the TFEQ and DEBQ in an exploratory fashion, and applied a Bonferroni correction to those comparisons.

One objective measure correlated with performance: waist to hip ratio was negatively related to hits – false alarms in the no distraction blocks of the food runs, $r = -.34$, $p < .01$, and in the no distraction blocks of the non-food runs, $r = -.26$, $p < .04$. There were two questionnaire measures which correlated with performance. Total scores on the restraint scale were related to hits – false alarms in the no distraction blocks of the food runs, $r = -.26$, $p < .04$, and in the no distraction blocks of the non-food runs, $r = -.25$, $p < .05$. PFS total scores were also negatively related to performance, but only in the no distraction blocks of the food runs, $r = -.26$, $p < .05$.

Curiously, the restraint scale, PFS, and waist to hip ratio were correlated with performance in the no distraction blocks, meaning when there was no distraction present. To explore this further, correlations were computed between the restraint scale, PFS scores, waist to hip ratio, and hits – false alarms in the first and fourth blocks of the no distraction conditions in each run. Restraint and PFS scores were correlated with performance in the fourth block in the food run, $r = -.25$ and -.24, $p = .05$, but not the first block, both $|r| < .21$, both $p > .10$. The restraint scale was also correlated with performance in the fourth block in the non-food run, $r = -.26$, $p < .05$, but not the first block, $r = .18$, $p > .15$. This indicates that these correlations with no distraction condition performance may have to do with failure to recover from distraction. In particular, it appears that the PFS correlation was tracking the ability to recover from the resistance to food-related information playing as distraction. Given the exploratory nature of this second wave of correlations, these results should be interpreted with caution. Waist to hip ratio was related to performance in the first and fourth blocks of the food no distraction run, $r = -.36$ and -.23, respectively, as well as the first and fourth blocks of the non-food no distraction run, r

= -.21 and -.25, respectively. Only the first food no distraction block, and the fourth non-food no distraction block reached statistical significance, $p < .01$ and $< .05$, respectively, the other correlations did not reach significance, *p*s > .06. This interpretation is somewhat less clear, but it seems that waist to hip ratio may be more generally related to performance.

Questionnaire analyses. We used a questionnaire measure from Berry et al. (2013) to assess the subjective experience of mindwandering and boredom during the video SAT. There were five items, including “At times of this task, it was hard for me to keep my mind from wandering,” “During the task, my thoughts seldom drifted from the subject before me,” “I was easily bored during this task,” “I had difficulty in keeping my attention focused on this long, tedious task,” and “No matter how hard I tried to concentrate, I felt easily distracted by the videos playing.” A sum score of these items was computed. There was no weight group difference in this score, $t(62) = .30$, $p > .75$, $d = .074$, and no diet group difference, $t(62) = 1.01$, $p > .30$, $d = .265$, indicating that participants did not have subjectively different experiences of the task.

We examined total accuracy scores on our video content quizzes, and found that overweight/obese individuals appeared to have encoded more information from the distracting videos than their lean peers, presumably because they paid more attention to the videos. Specifically, overweight/obese participants had higher scores in the non-food condition (M = 7.63, SE = 0.48) than their lean peers (M = 6.25, SE = 0.50), $t(62) = -1.99$, $p = .052$, $d = -.497$, and significantly higher scores (M = 10.53, SE = 0.39) than their lean peers (M = 8.53, SE = 0.60) in the food condition, $t(62) = -2.78$, $p < .01$, $d = -.710$. Overall, scores were significantly higher in the food condition than the non-food condition, $t(63) = 6.96$, $p < .0001$, $d = .871$. Dieters did not have higher scores than non-dieters in either questionnaire measure, both $t < 1$, both $p > .4$ ($M_{dieters} = 9.91$, $SE = 0.55$, $M_{non\text{-}dieters} = 9.33$, $SE = 0.50$ for food; $M_{dieters} = 7.05$, $SE = 0.49$, $M_{non\text{-}dieters} = 6.88$, $SE = 0.48$ for non-food).

We computed correlations between the self-reported mindwandering measure, the food questionnaire accuracy, and the non-food questionnaire accuracy, and hits – false alarms in the distraction and no distraction conditions of the food and non-food runs. These analyses were partially consistent with what we would have predicted (that better performance on the questionnaire measures would correlated with worse performance on the main task). Self-reported mindwandering was significantly correlated with performance in the food no distraction ($r = -.28$, $p < .03$), non-food no distraction ($r = -.31$, $p < .02$), and non-food distraction, ($r = -.29$, $p < .03$) blocks, but not the food distraction block ($r = -.21$, $p = .10$). Food questionnaire accuracy was significantly related to performance in the food distraction block ($r = -.25$, $p < .05$) and the non-food distraction block ($r = -.25$, $p < .05$), but not the no distraction blocks, both $|r| < .17$, both $p > .2$. Non-food questionnaire accuracy was significantly related only to performance in the non-food distraction block ($r = -.25$, $p < .05$), all other $|r| < .10$, all $p > .4$.

Summary

In sum, there was no evidence from the video SAT results to support our predictions that overweight/obese individuals, and dieters would show differential susceptibility to the video distraction manipulation, nor evidence that this susceptibility would be maximal for food-related distraction. Overweight/obese individuals did show evidence of having paid more attention and thus encoded more content of the distractors, but this was not related as predicted to worse performance in the specific block from which the content sampled in the quiz was taken. Finally, Restraint and PFS scores tracked some performance indices, as predicted, but again, not in the actual distraction blocks, as we would have hypothesized. Perhaps our task was too easy, and though some individuals may have been more distracted than others, the main task was easy enough that this increased distraction did not result in performance decrements. We now move to the image SAT analyses and consider the implications of both task results below in the general discussion.

Image SAT Results

Non-response data. We first analyzed non-response data for all runs. Mean rates of non-response were low overall, with a mean of 2.3% (*SD* = 4.6%) for signal-absent trials in no distraction runs, and a mean of 1.3% (*SD* = 2.5%) for signal-present trials in the no distraction runs. The mean for bird distraction signal-absent trials was 1.9% (*SD* = 1.5%), and for signal-present trials was 0.8% (*SD* = 2.6%). The mean for food signal-absent trials was 1.3% (*SD* = 7.1%) and for food signal-present trials was 0.4% (*SD* = 1.6%). There were no significant group differences in non-response data for any of these levels, all $|t| < 1.7$, all $p > .10$. There were also no differences in non-response data between the food and bird distraction runs, both $t(63) < 1$, both $p > .3$.

In examining the non-response data, we identified one normal weight participant who had failed to respond to more than one quarter of all trials in the distraction runs, as high as 91% in some conditions. This subject was therefore excluded from d′ analyses below.

Weight groups analysis. Contrary to our hypothesis and our previous results, overweight/obese participants did not perform more poorly, even numerically. See Table 4.6 for Image SAT data. Weight groups showed consistent performance regardless of distraction condition or distraction type. We first analyzed average performance in the two distraction runs compared with average performance in the no distraction runs. This analysis revealed only a main effect of distraction, $F(1, 61) = 66.54$, $p < .0001$, $\eta_p^2 = .522$, with higher average d′ in the no distraction runs (*M* = 3.59, *SE* = 0.08) than in the distraction runs, (*M* = 3.08, *SE* = 0.09). There were no other significant effects, *F*s < 1, *p*s > .7. Planned comparisons revealed no significant group differences, both |*t*| < 1, both *p* > .7, however unlike all previous investigations using a version of SAT or dSAT, overweight/obese participants here had slightly numerically higher d′ means than their lean peers.

Examining the no distraction runs in more detail in an ANOVA including d′ from the first and last no distraction blocks and group, yielded only a main effect of block, $F(1, 61) = 27.30$, $p < .0001$, $\eta_p^2 = .309$, all other $F < 1$, $p > .6$. This main effect of block was due to better performance in the first block (*M* = 3.79, *SE* = 0.85) than in the last block (*M* = 3.34, *SE* = 0.90). Planned comparisons showed no significant group differences between normal weight and overweight participants, all |*t*| < 1, all *p* > .6.

Repeating this analysis breaking the data down by signal duration revealed a main effect of block, $F(1, 61) = 27.28$, $p < .0001$, $\eta_p^2 = .309$, and a main effect of signal duration, $F(2, 122) = 97.71$, $p < .0001$, $\eta_p^2 = .616$, with no other significant effects, *F*s < 1.5, *p*s > .2. The main effect of signal duration was due to the predicted pattern of 34 ms signals (*M* = 3.35, *SE* = 0.08) being harder than 50 ms signals (*M* = 3.85, *SE* = 0.09), which were also harder than 150 ms signals (*M* = 4.08, *SE* = 0.09). Planned comparisons showed no significant differences between groups at any signal duration either overall or broken down by group, all |*t*| < 1, all *p* > .3.

An ANOVA including overall d′ in the bird and food distraction runs, along with group, showed no significant main effects or interactions, all $F < 1.2$, all $p > .2$. Planned comparisons showed no differences in performance in bird or food d′ between groups, both |*t*| < 1, both *p* > .6. Repeating this analysis including signal duration revealed only a main effect of signal duration, $F(2, 122) = 191.23$, $p < .0001$, $\eta_p^2 = .758$, all other $F < 1.4$, all $p > .2$. The main effect of signal duration was again due to 34 ms being harder than 50 ms, which were also harder than 150 ms signals, and this pattern was true of both bird (*M* = 2.80, 3.62, 3.99, *SE* = 0.10, 0.12, 0.10, respectively) and food trials (*M* = 2.73, 3.51, 3.92, *SE* = 0.10, 0.13, 0.12, respectively). Planned comparisons revealed no significant group differences, all $|t| < 1$, all $p > .3$.

Diet groups analysis. Again contrary to our hypothesis, although consistent with our own previous results, we found no effects of dieting behaviour on any performance metric. We first analyzed average performance in the two distraction runs compared with average performance in the no distraction runs. This analysis revealed only a main effect of distraction, $F(1, 61) = 63.82$, $p < .0001$, $\eta_p^2 = .511$, with higher average d′ in the no distraction runs than in the distraction runs, as reported above. There were no other significant effects, *F*s < 1, *p*s > .5. Planned comparisons revealed no significant diet group differences, both $|t| < 1$, both $p > .5$.

Examining the no distraction runs in more detail in an ANOVA including d′ from the first and last no distraction blocks and group, yielded only a main effect of block, $F(1, 61) = 24.76$, $p < .0001$, $\eta_p^2 = .289$, all other $F < 1$, $p > .6$. This main effect of block was due to better performance in the first block than in the last block, as reported previously. Planned comparisons showed no significant differences between diet groups, all $|t| < 1$, all $p > .6$.

Repeating this analysis breaking the data down by signal duration revealed a main effect of block, $F(1, 61) = 24.44$, $p < .0001$, $\eta_p^2 = .286$, and a main effect of signal duration, $F(2, 122) = 88.72$, $p < .0001$, $\eta_p^2 = .593$, with no other significant effects, *F*s < 1, *p*s > .4. The main effect of signal duration was due to the predicted pattern of increasing d′ with increasing signal duration reported above. Planned comparisons showed no significant differences between diet groups at any signal duration either overall or broken down by group, all $|t| < 1.2$, all $p > .25$.

An ANOVA including overall d′ in the bird and food distraction runs, along with group, showed no significant main effects or interactions, all $F < 1.4$, all $p > .2$. Planned comparisons showed no differences in performance in bird or food d′ between groups, both $|t| < 1$, both $p > .7$. Repeating this analysis including signal duration revealed a main effect of signal duration, $F(2, 122) = 173.98$, $p < .0001$, $\eta_p^2 = .740$, again due to increasing d′ with increasing signal duration. There was also a category by signal duration by dieting interaction, $F(2, 122) = 8.04$, $p = .0005$, $\eta_p^2 = 0.116$, however, planned comparisons revealed no significant group differences, all $|t| < 1.5$, all $p > .14$.

Correlation analysis. We repeated the correlational analysis reported above for the video SAT, this time using d′ from the no distraction runs, bird and food runs. There were no significant correlations between any of the variables, all $|r| < .24$, all $p > .06$. Thus, again inconsistent with our predictions, none of our measures of food-related thought or behaviour was relate to performance in the image SAT.

Discussion

The results from two tasks in Experiment 3 were inconsistent with our hypothesis that overweight/obese and dieting individuals would be more vulnerable to distraction in sustained attention, specifically under food-related distraction conditions. The video SAT results indicated that overweight and normal weight participants, and dieting and non-dieting participants performed equivalently well in the baseline condition and with distraction from food and non-food videos. Interestingly, it seemed that overweight/obese subjects recalled more of the content for the distracting videos, particularly for the food videos. This may indicate that they were dividing their attention quite efficiently between the task and the distraction, and that if the task had been more challenging, such efficient attentional division would not have been possible, perhaps then leading to some observable performance decrement. Additionally, some measures of restraint and the appetitive influence of food (PFS scores) were negatively related to performance on the task following exposure to distraction. Perhaps individuals high on these trait measures were able to suppress or restrain thoughts provoked by the distraction for a time, but subsequently ruminated about it, or experienced some rebound in thoughts about the distraction that was unhelpful to subsequent performance. Future studies should probe this possibility in a more targeted way, as these explanations are speculative.

Results from our image SAT again showed no evidence that overweight/obese individuals had any compromised ability to resist distraction, neither generally nor specifically to food. These results were in stark contrast to what we expected based on our previous dSAT experiment, in which strobing distraction affected performance quite clearly in overweight/obese individuals. Again, these results were inconsistent with our predictions. Some task design features may have contributed to the lack of group differences. In particular, because we were worried about how visually complex our distracting images were, we blocked off the three possible signal locations in silver throughout the task. This no doubt provided a level of scaffolding or structure to the task that previously did not exist, directing visual attention to the possible signal locations, and supporting monitoring functions. Additionally, we slowed the strobing rate to 2 Hz (from 10 Hz previously), but we kept the number of flashing screens between the signal and cue to response the same. This resulted in an increase in the time to process the signal from half a second to two and a half seconds. Finally, we allowed participants one and a half seconds to respond instead of one second, as we had used previously. We made these changes in an effort to respond to the increased subjective difficulty of processing the visually complex distractor images, however, this also resulted in a fundamentally different time scale for cognitive processing in this task. If previously documented deficits were in part due to the high demand of processing the signal and response cues quickly, then it is consistent to expect these difficulties to be ameliorated with more generous processing time parameters. Reverting back to the time scale used in our previous study would allow the assessment of this hypothesis.

One result from the present set of experiments was consistent with our previous study, which is that dieting was not a good predictor of performance. Despite some previously published reports that implicated dieting as a predictor of poor sustained attention performance most of our results from modified versions of the SAT (or the CTET) have shown no effects of dieting. This may be due to differences in task design or participant selection, which can be examined in future studies, but what is clear is that there are at least some contexts in which dieting does not appear to have adverse cognitive effects on attentional performance.

General Discussion

In the first two experiments, the sensitivity index d′ showed that overweight/obese individuals performed more poorly in the SAT and dSAT compared with their lean peers. These differences in performance were larger under conditions of distraction; however only in Experiment 1 were the comparisons statistically significant. In Experiment 3, there were no consistent effects of weight group, in conflict with our hypotheses and results from Experiments 1 and 2. In addition, despite previously published reports of impaired vigilance or sustained attention in dieting individuals (e.g., Byrne, Cooper, & Fairburn, 2003; Kretsch et al., 1998; Ward & Mann, 2000; Williams et al., 2002), our results showed inconsistent effects across three experiments. There were neither consistent group differences between current dieters and current non-dieters, nor were there consistent correlations between performance and other measures of food-related attitudes and behaviour. Each of these results merits further consideration.

First, the results of Experiment 1 suggest an impairment not in sustained attention *per se*, but in controlling challenges to sustained attention presented by task-extrinsic distraction. In this case, the distraction was in the form of a strobing screen. Though overweight/obese individuals performed more poorly overall, the group difference only became significant statistically in the distraction condition. This interaction suggests that some process required to maintain focused attention in order to detect signals and/or select responses may be compromised in overweight individuals. Interestingly, and unlike previous results in the working memory domain, the strongest correlations with performance were with BMI. In the working memory domain, other measures like worry about weight and restrained eating were better predictors of performance, whereas in the sustained attention domain, overweight *per se* (indexed by BMI or visual adiposity ratings) appears to be the best predictor of performance. It should also be noted that even though group differences were not as large in the baseline SAT condition, there was a significant negative correlation between BMI and d′, indicating that higher BMI was associated with poorer performance. The *r* values were of similar magnitude in the SAT and dSAT conditions.

Experiment 2 served as a partial replication in that the overall pattern of performance was preserved—overweight/obese individuals performed more poorly, especially in the dSAT. However, these results failed to reach statistical significance. Notably, Experiment 1 data were collected at the end of a one and a half to two hour testing session, while Experiment 2 data were collected at the beginning of an experimental session. It is possible that the magnitude of the effects in Experiment 1 was due to fatigue influencing performance differentially in the overweight/obese group. It is possible that having to complete one to two hours of tasks exhausted a finite pool of resources which participants would normally draw upon to complete the challenging distractor condition of the SAT. In overweight/obese individuals, this resource pool could be smaller in the first place, or the vulnerability to distraction could be greater, requiring the use of more focused resources to achieve the same level of performance. Thus, in the presence of mental fatigue, the overweight/obese individuals showed greater performance decrements. In contrast, in Experiment 2, participants began their experimental session only with a consent and demographics form before starting to complete the SAT and dSAT. Thus, there would be no cognitive depletion or exhaustion in this case, perhaps contributing to the subtle effects of weight group documented in this experiment. In support of this admittedly speculative possibility, overall rates of non-responses were considerably higher in the first compared with the second experiment. Specifically, comparing the average non-response data from the two dSAT runs in Experiment 2 with the non-response data from the dSAT run in Experiment 1 showed that all rates of non-responses (e.g., in SAT and dSAT signal-present and signal-absent trials) were significantly higher in Experiment 1 (all $t(97) > 2$, all $p < .05$). This is consistent with what would be expected under conditions of mental fatigue. Future research can systematically assess this possibility by having participants complete one run of dSAT at the beginning of a testing session and one at the end of the same session, interleaved with other challenging cognitive tasks, to assess the difference in performance between the first and last dSAT runs.

In Experiment 3, there were no robust effects of weight or dieting status. We attribute the failure to find such effects (even numerically) in part to some of the features of our task designs, as discussed above. However, we also note that this third experiment serves as an important indication that though there may be weight-related poor performance under conditions of distraction in sustained attention in some contexts, the evidence does not indicate that this poor performance occurs in all conditions or at all levels of task difficulty. Furthermore, this experiment highlights that despite reports of food-specific deficits in performance, there are contexts in which food-related stimuli do not serve as more potent distractors, and contexts in which food-related stimuli do not produce differential performance in normal weight versus overweight participants. Future research can further identify the factors that delimit such effects in overweight/obese individuals.

Considered together, the majority of the weight group results certainly point to some difficulty in controlling attention in the presence of distraction for overweight/obese individuals. However, despite multiple previous reports of objective and subjective differences in sustained attention or vigilance in dieting samples, our data were not consistent with the hypothesis that dieting is associated with impaired sustained attention or vigilance, even in the distraction conditions. There are a number of possible explanations for the difference between our results and previous documentations of a dieting effect; however, it is first worth noting that other studies have failed to find effects of dieting or food deprivation on sustained attention performance (Green et al., 1997; Kretsch et al., 1997). First, previous studies used tasks that had strong relationships to other measures of executive function, and did not possess similar task characteristics to the SAT and dSAT. In particular, the d2 and Bakan tests used in previous reports require attention, but, for example, they do not manipulate signal duration and do not require responses on each trial, and may in fact draw more heavily on selective attention. Perhaps these differences in task formatting, or the requirement to respond on each trial negate any dieting-related effects. For example, a task where participants are reminded to respond on each trial may provide a level of structure to support optimal performance that is missing from tasks in which the decision of whether or not to respond is left entirely up to the subject.

Additionally, a sustained attention task that also has high attentional selection demands could capture poorer performance by dieting participants as a result of decrements in either selective or sustained attention performance. It is also possible that since our sample consisted of young, healthy adults of both genders, dieters were not as affected by caloric restriction. In previous reports, women who were dieting had poor sustained attention, but this was tied strongly to hemoglobin and other metrics of iron deficiency. Perhaps our younger, mixed gender sample was not as vulnerable to this. Additionally, we only characterized dieters using questionnaire measures, and did not obtain corroborating evidence about how much caloric restriction they engaged in. Thus, our dieting and restraint constructs were fundamentally psychological measures of beliefs about food restriction and dieting behaviour. There is an established literature about unintentional misreporting and miscalculation of meal caloric content (Carels, Konrad, & Harper, 2007; Chandon & Wansink, 2007; Cottrell & Chambers, 2013; Lansky & Brownell, 1982; Lichtman et al., 1992; Stanton & Tips, 1990; Vance, Woodruff, McCargar, Husted, & Hanning, 2009; Wansink & Chandon, 2006; Zegman, 1984), so perhaps our dieters were not actually restricting calories in a way that would yield a decrement in Hb or other biological markers that have been linked to impaired attentional control in previous reports. Combined with evidence suggesting that restrained eaters may take in more calories than their non-restrained peers (e.g., Goldstein, Katterman, & Lowe, 2013; Stice, Fisher, & Lowe, 2007), our measures of dieting and restrained eating may index feelings of deprivation rather than actual caloric restriction.

One additional avenue for future research would be to manipulate the salience of the food cues employed in an experimental design such as the one employed in Experiment 3. In particular, there is evidence from the addiction literature suggesting that attentional biases are most prominent when the possibility of obtaining the food (or drug, cigarette, alcohol, in many studies of addiction) is proximal or primed. In previous studies, offering a small "appetizer" to participants before task performance enhanced attentional bias effects (Overduin, Jansen, & Louwerse, 1995), and in studies of addiction, when participants know they may later be granted the opportunity to use or consume the substance they abuse, the attentional bias effects emerge strongly (Field & Cox, 2008). If there is a susceptibility to distraction in sustained attention that is related to this type of attentional bias toward food cues, it is most likely to be strongly expressed under such conditions as a prime or promise of appetitive food consumption.

Overall, we have mixed results regarding the influence of obesity on cognitive control in the sustained attention domain. Though we had initially hypothesized that, similar to our results in the working memory domain, there would be some food-specific vulnerability to distraction, we see no evidence of any food-specific effects on performance. There are a number of differences between our approaches in the memory and attention domains, however, given that our attentional experiments use food-related videos and images, which are thought to be more salient and ecologically valid than the verbal stimuli used in our working memory studies, we conclude that if there are food-specific effects to be found, they are weaker or perhaps more sensitive to other traits or states like craving, addiction to food, or disordered eating that were not the focus of the selection of our current sample.

Future studies can include more difficult sustained attention manipulations to examine effects of the types of food-related distractors employed in Experiment 3, and to systematically manipulate hunger[24] or craving, to see if increasing the salience of those types of processes would also result in the emergence of food-specific performance detriments. Preliminarily, we suggest that sustained attention performance is not compromise globally in obesity, but that there is a vulnerability to task-extrinsic distraction in at least some contexts. One additional future manipulation would be to include some kind of task-relevant and task-intrinsic distraction in the sustained attention domain to assess whether the type increased distractibility documented using such distractors in working memory generalizes to the sustained attention domain. Though it is difficult to interpret null results, the present experiments do make an important contribution, as claims of universal performance impairments, attentional biases, and other relationships between eating behaviour and performance do have limits. Further exploring and delineating the limits of such performance effects are critical to understanding any deficits or vulnerabilities that do exist.

[24] Subjective hunger ratings on a scale from one to ten collected at the end of the experiment to assess current hunger and hunger at the beginning of the experiment for Experiments 1, 2, and 3 in this chapter were not related to average SAT or dSAT d′ in Experiment 1 or 2, Hits – False Alarms in distraction or no distraction blocks of the Video SAT, nor d′ in the Image SAT (all $|r| < .25$, all $p > .1$).

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Table 4.1 Participant characteristics for Experiments 1 and 2

	Experiment 1		Experiment 2	
	NW	OW	NW	OW
N	29	24	23	23
Age	19.6 (1.9)	19.4 (1.1)	20.3 (1.9)	20.6 (1.7)
Percent Female	65.52%	66.67%	47.8%	47.8%
Years of Education	13.8 (1.6)	13.6 (1.3)	14.5 (1.5)	14.9 (1.2)
BMI	22.0 (1.7)	29.7 (4.5)***	22.0 (2.2)	30.1 (6.3)***
Average Adiposity Ratings	1.8 (0.3)	3.2 (0.6) ***	1.8 (0.4)	3.0 (0.7)***
DEBQ Restraint	2.60 (0.16)	2.80 (0.15)	2.35 (0.18)	2.84 (0.17) †
DEBQ External Eating	3.28 (0.08)	3.25 (0.09)	3.39 (0.09)	3.22 (0.12)
DEBQ Emotional Eating	2.35 (0.13)	2.68 (0.21)	2.29 (0.13)	2.64 (0.21) †
TFEQ Uncontrolled Eating	2.31 (0.10)	2.29 (0.10)	2.41 (0.10)	2.31 (0.15)
TFEQ Cognitive Restraint	2.70 (0.14)	2.68 (0.13)	2.30 (0.16)	2.72 (0.19) †
TFEQ Emotional Eating	1.86 (0.11)	2.22 (0.20)	1.91 (0.15)	2.07 (0.18)
Overweight Preoccupation	2.28 (0.17)	2.60 (0.20)	2.18 (0.20)	2.78 (0.20)*
Current Dieting Status	1.59 (0.18)	2.46 (0.27)**	1.70 (0.19)	2.34 (0.29) †
Restraint Scale Total	13.00 (1.00)	18.04 (0.86) ***	12.45 (1.25)	18.50 (1.33)*

Note. NW = Normal Weight; OW = Overweight/obese. Age, Years of Education, BMI, and Adiposity Ratings are *M* (*SD*). All other measures are *M* (*SE*). *** = $p < .0001$, ** = $p < .01$, * = $p < .05$., † = $p < .10$.

Table 4.2 d′ values by weight group in Experiment 1.

	Normal Weight	Overweight
SAT Blocks by Signal Duration		
SAT Block 1 34 ms	4.09 (0.15)	3.87 (0.18)
SAT Block 1 50 ms	4.36 (0.13)	4.09 (0.18)
SAT Block 1 150 ms	4.44 (0.11)	4.09 (0.17)
SAT Block 4 34 ms	3.96 (0.17)	3.62 (0.19)
SAT Block 4 50 ms	4.29 (0.12)	3.98 (0.18)
SAT Block 4 150 ms	4.22 (0.13)	4.22 (0.14)
dSAT Blocks by Signal Duration		
dSAT Block 2 34 ms	2.56 (0.21)	1.61 (0.24)
dSAT Block 2 50 ms	3.31 (0.30)	2.56 (0.29)
dSAT Block 2 150 ms	3.79 (0.14)	3.26 (0.21)
dSAT Block 3 34 ms	2.61 (0.23)	2.33 (0.26)
dSAT Block 3 50 ms	3.23 (0.26)	2.98 (0.36)
dSAT Block 3 150 ms	3.76 (0.18)	3.34 (0.32)
Overall by Signal Duration		
SAT Overall 34 ms	3.88 (0.14)	3.63 (0.17)
SAT Overall 50 ms	4.23 (0.11)	3.92 (0.17)
SAT Overall 150 ms	4.23 (0.11)	4.07 (0.14)
dSAT Overall 34 ms	2.39 (0.18)	1.78 (0.20)
dSAT Overall 50 ms	3.22 (0.21)	2.53 (0.27)
dSAT Overall 150 ms	3.64 (0.15)	3.07 (0.23)
Overall by Block		
SAT Block 1 Overall	4.16 (0.12)	3.88 (0.17)
SAT Block 4 Overall	3.99 (0.14)	3.71 (0.16)
dSAT Block 2 Overall	2.90 (0.18)	1.95 (0.22)
dSAT Block 3 Overall	2.88 (0.20)	2.57 (0.27)
Overall		
SAT Overall	3.98 (0.11)	3.73 (0.15)
dSAT Overall	2.72 (0.17)	2.09 (0.20)

Note. All measures are *M*(*SE*)

Table 4.3 d′ values by weight group in Experiment 2.

	Normal Weight	Overweight
SAT Runs		
SAT 34 ms	3.84 (0.14)	3.65 (0.13)
SAT 50 ms	4.09 (0.12)	3.97 (0.12)
SAT 150 ms	4.26 (0.11)	4.35 (0.09)
SAT Overall	3.99 (0.13)	3.83 (0.12)
dSAT Runs		
SAT 34 ms	3.72 (0.13)	3.56 (0.15)
SAT 50 ms	4.12 (0.13)	4.06 (0.15)
SAT 150 ms	4.33 (0.10)	4.26 (0.13)
SAT Overall	3.83 (0.11)	3.74 (0.13)
dSAT 34 ms	2.27 (0.20)	2.04 (0.20)
dSAT 50 ms	2.83 (0.21)	2.60 (0.21)
dSAT 150 ms	3.53 (0.16)	3.41 (0.19)
dSAT Overall	2.59 (0.18)	2.39 (0.18)

Note. All measures are *M*(*SE*)

Table 4.4 Participant characteristics for Experiment 3

	Normal Weight	Overweight
N	32	32
Age	19.4 (1.2)	19.2 (1.0)
Percent Female	65.63%	62.50%
Years of Education	13.3 (0.9)	13.3 (1.2)
BMI	21.5 (1.9)	29.5 (4.8)***
Average Adiposity Ratings	1.8 (0.5)	3.2 (0.8)***
Waist to Hip Ratio	0.82 (0.07)	0.86 (0.07)*
DEBQ Restraint	2.49 (0.13)	2.83 (0.09)*
DEBQ External Eating	3.52 (0.09)	3.47 (0.09)
DEBQ Emotional Eating	2.74 (0.15)	2.72 (0.14)
TFEQ Uncontrolled Eating	2.48 (0.07)	2.41 (0.10)
TFEQ Cognitive Restraint	2.55 (0.12)	2.75(0.09)
TFEQ Emotional Eating	2.31 (0.13)	2.30 (0.12)
Overweight Preoccupation	2.33 (0.15)	2.76 (0.13)*
Current Dieting Status	1.69 (0.18)	2.38 (0.24)*
Restraint Scale Total	12.55 (0.73)	16.82 (0.89)***
YFAS Symptom Count	1.84 (0.21)	2.31 (0.31)
FCI Total	60.03 (2.98)	61.68 (3.06)
BIS Total	63.91 (1.98)	62.58 (1.93)
PFS Total	2.64 (0.14)	2.77 (0.16)

Note. Age, Years of Education, BMI, Adiposity Ratings, and Waist to Hip Ratio are *M* (*SD*). All other measures are *M* (*SE*). *** = $p < .0001$, ** = $p < .01$, * = $p < .05$., † = $p < .10$.

Table 4.5 Video SAT performance data by weight group in Experiment 3.

	Normal Weight	Overweight
Food Runs		
Overall No Distraction	94.63 (1.12)	94.09 (1.27)
Overall Distraction	90.94 (1.90)	92.84 (1.86)
No Distraction Block 1	94.97 (1.35)	94.97 (1.25)
No Distraction Block 4	94.06 (1.42)	92.88 (1.66)
Distraction Block 2	92.41 (2.07)	93.47 (1.49)
Distraction Block 3	89.25 (2.23)	92.09 (2.45)
Non-Food Runs		
Overall No Distraction	93.38 (1.39)	91.88 (1.65)
Overall Distraction	92.22 (1.56)	91.53 (2.08)
No Distraction Block 1	93.31 (1.41)	93.31 (1.63)
No Distraction Block 4	93.19 (1.52)	90.19 (2.22)
Distraction Block 2	93.34 (1.35)	92.34 (2.23)
Distraction Block 3	91.00 (2.17)	90.88 (2.07)

Note. All measures are Hits-False Alarms, *M*(*SE*)

Table 4.6 Image SAT d′ data by weight group in Experiment 3.

	Normal Weight	Overweight
Overall		
No Distraction Block 1	3.75 (0.12)	3.82 (0.12)
No Distraction Block 4	3.30 (0.12)	3.37 (0.13)
Bird Distraction	3.08 (0.14)	3.16 (0.13)
Food Distraction	3.02 (0.13)	3.06 (0.16)
By Signal Duration		
No Distraction Block 1 34 ms	3.54 (0.14)	3.57 (0.14)
No Distraction Block 1 50 ms	4.11 (0.13)	4.22 (0.13)
No Distraction Block 1 150 ms	4.31 (0.11)	4.37 (0.11)
No Distraction Block 4 34 ms	3.05 (0.13)	3.22 (0.14)
No Distraction Block 4 50 ms	3.75 (0.16)	3.62 (0.17)
No Distraction Block 4 150 ms	3.81 (0.14)	3.94 (0.17)
Bird Distraction 34 ms	2.76 (0.13)	2.83 (0.15)
Bird Distraction 50 ms	3.53 (0.20)	3.70 (0.16)
Bird Distraction 150 ms	3.98 (0.15)	4.00 (0.14)
Food Distraction 34 ms	2.74 (0.12)	2.71 (0.17)
Food Distraction 50 ms	3.37 (0.18)	3.63 (0.19)
Food Distraction 150 ms	3.85 (0.16)	3.98 (0.18)

Note. All measures are *M*(*SE*)

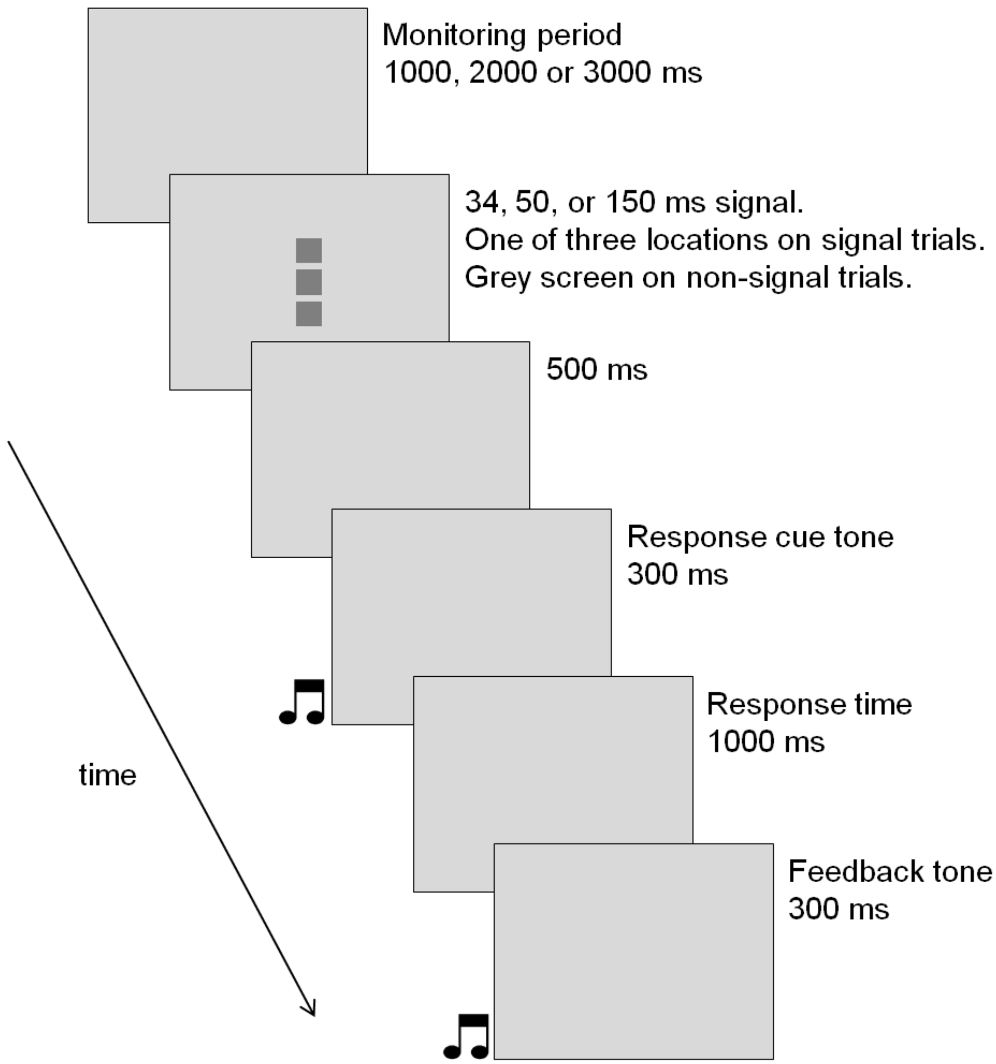

Figure 4.1 SAT diagram. dSAT parameters were identical, except that the screen alternated between silver and black throughout at 10Hz.

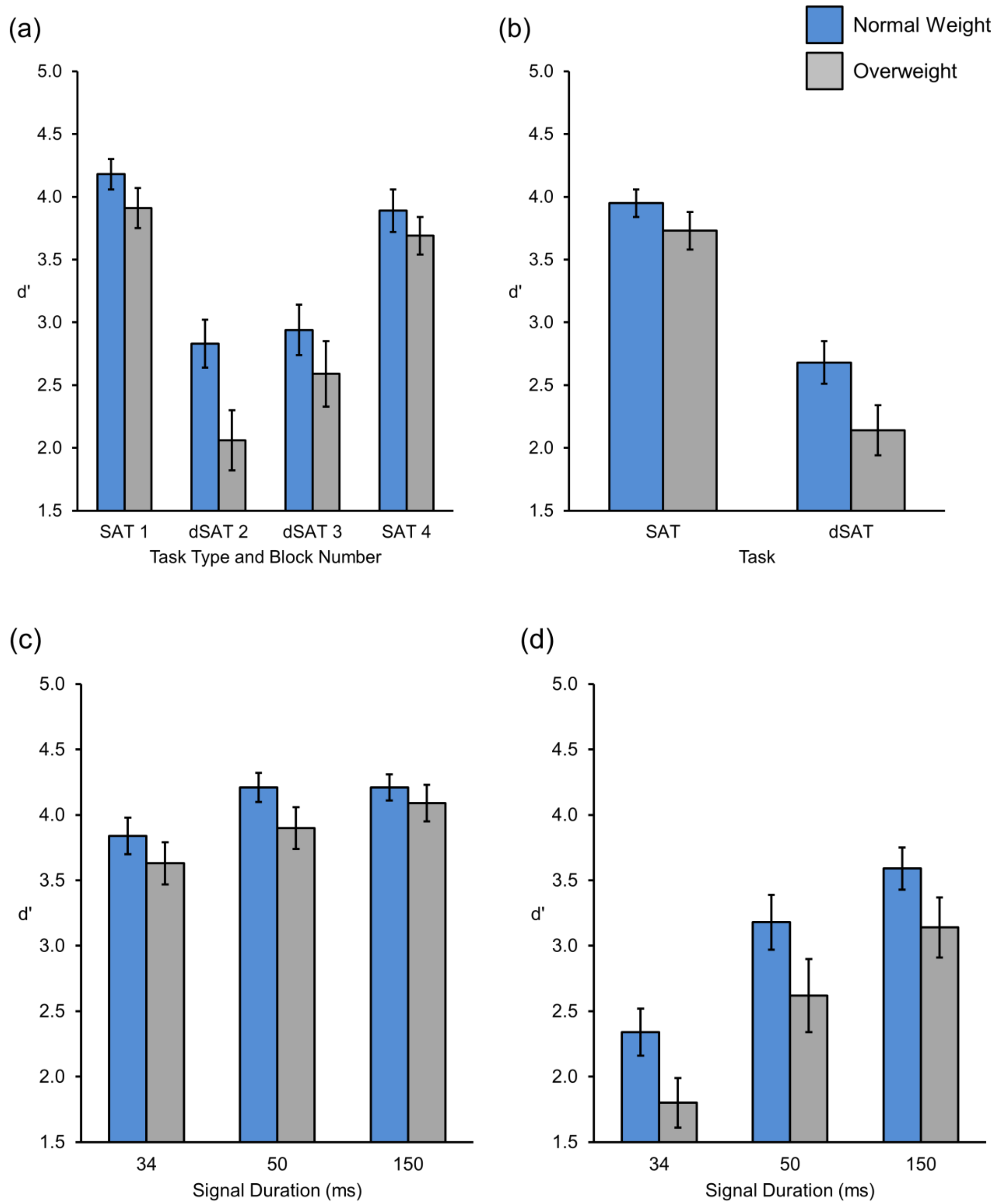

Figure 4.2 Experiment 1 d′ (a) by task type and block, (b) overall by task type, (c) by signal duration in SAT blocks, (d) by signal duration in dSAT blocks.

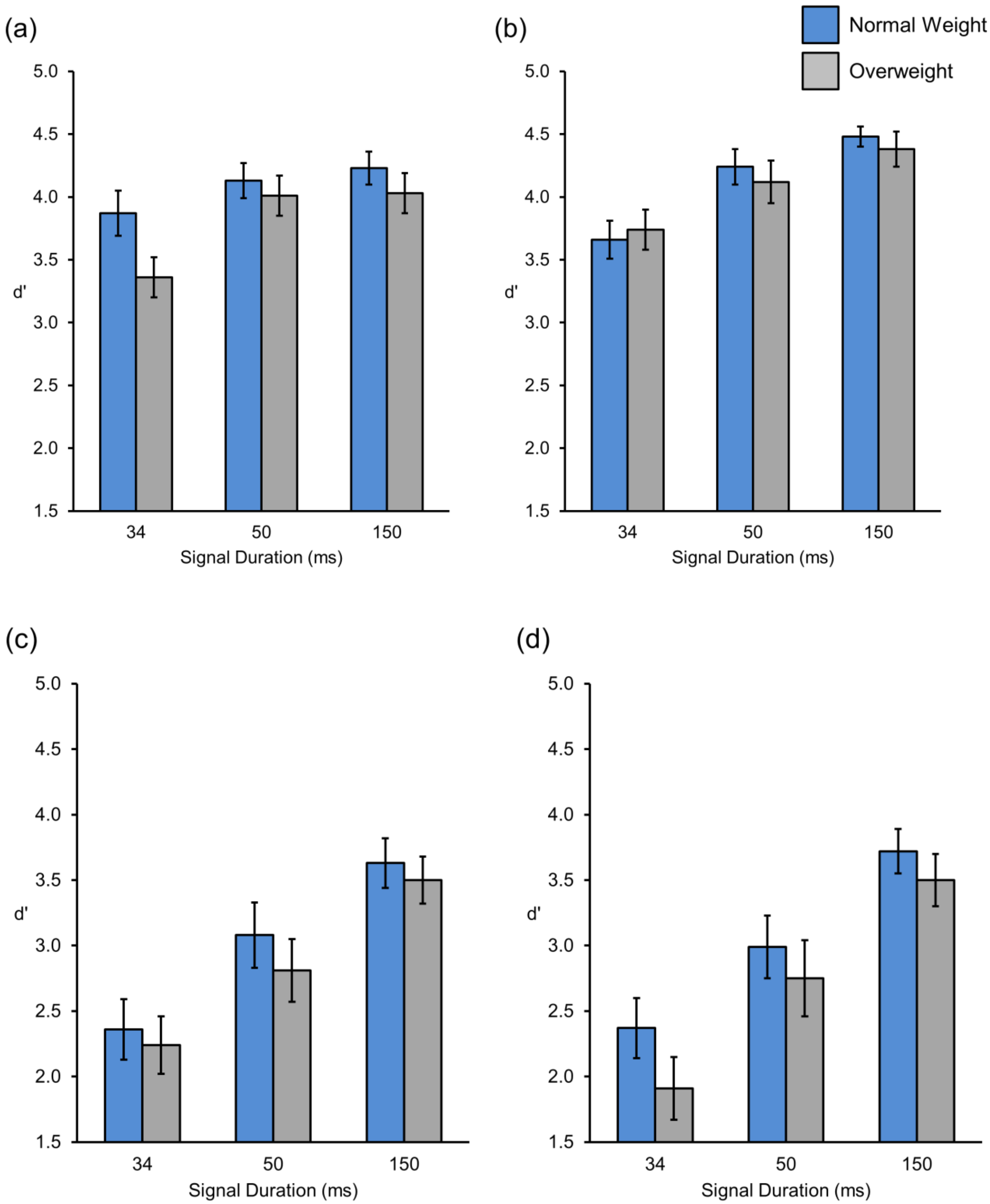

Figure 4.3 Experiment 2 d′ by signal duration (a) SAT trials in dSAT Run 1, (b) SAT trials in dSAT Run 2, (c) dSAT trials in dSAT Run 1, and (d) dSAT trials in dSAT Run 2.

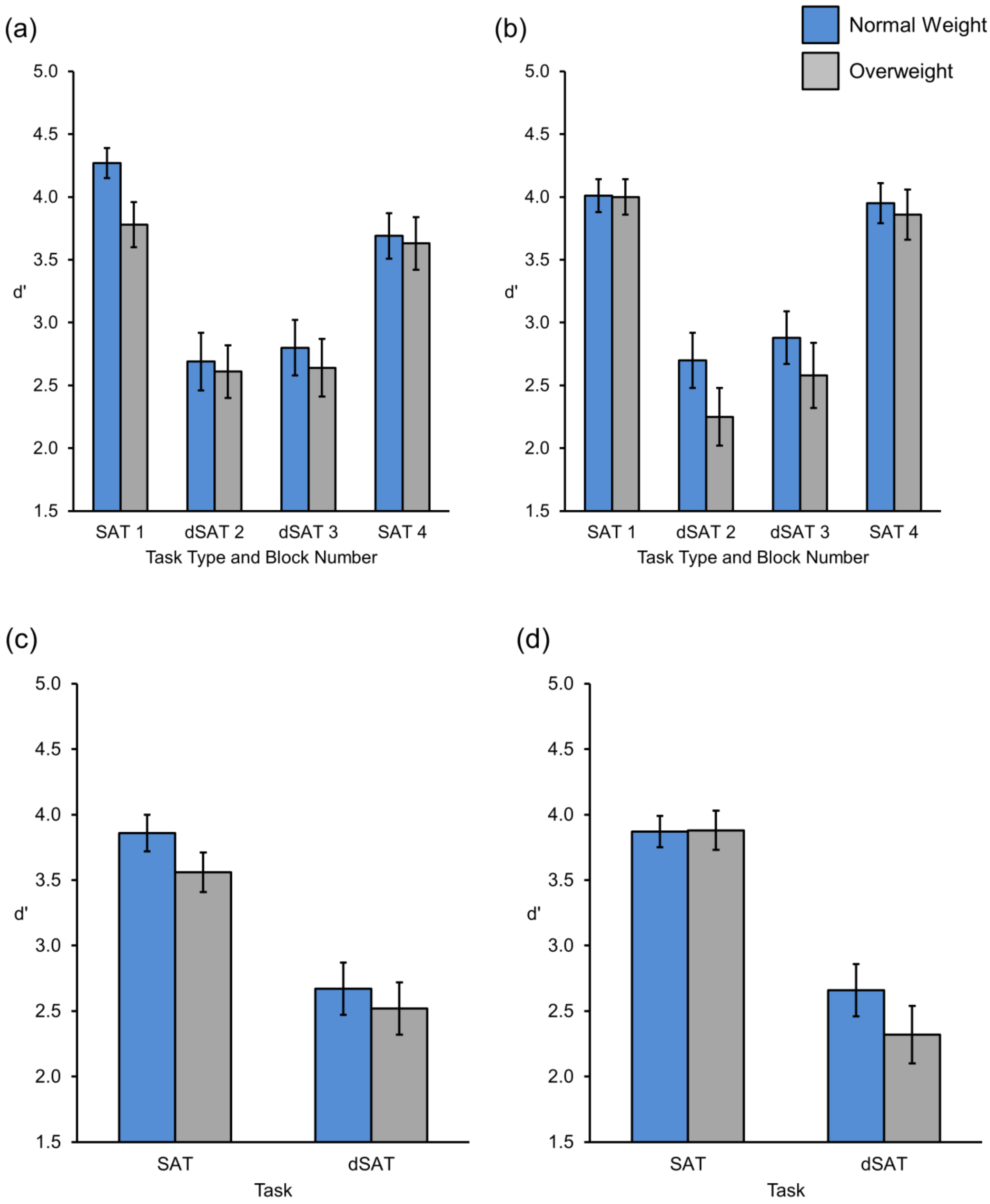

Figure 4.4 Experiment 2 d′ by task type and block number for (a) dSAT Run 1 and (b) dSAT Run 2. Overall d′ by task type for (c) dSAT Run 1 and (d) dSAT Run 2.

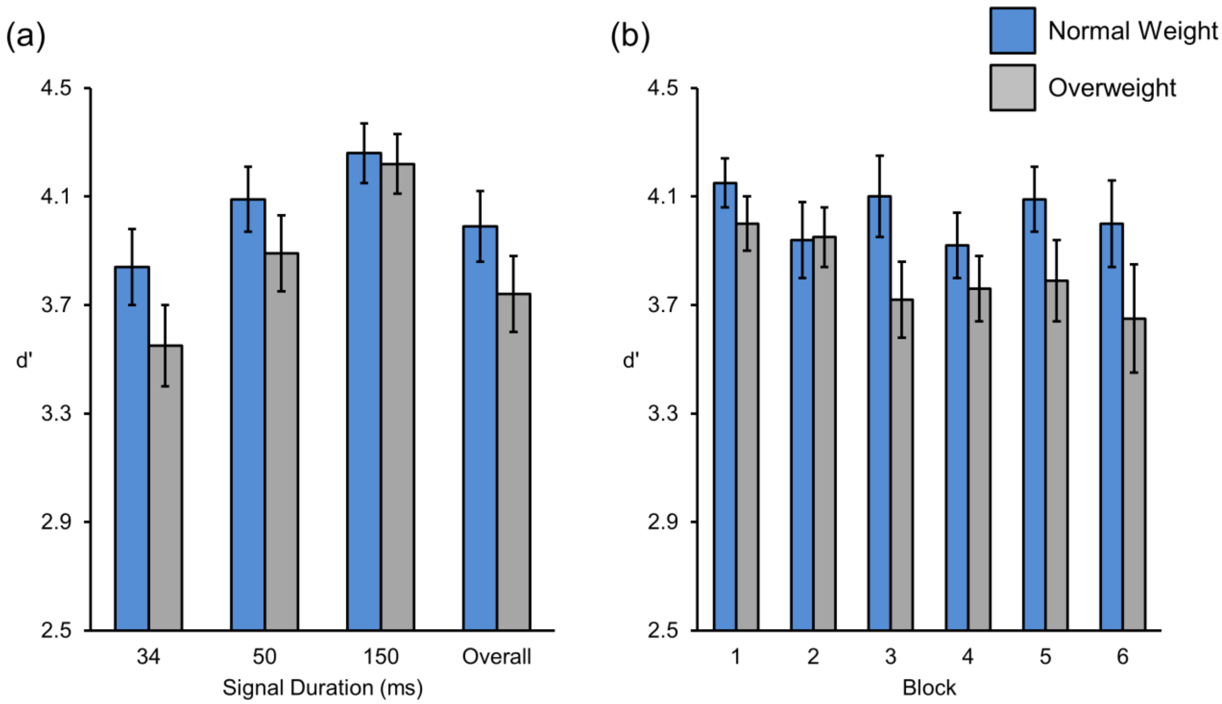

Figure 4.5 Experiment 2 d′ in SAT runs (a) by signal duration (b) by block.

CHAPTER V

Conclusion

The scientific aims outlined at the beginning of this dissertation were to determine whether or not obesity is associated with increased vulnerability to task-intrinsic and/or task-extrinsic distraction, and to determine whether these effects are more pronounced when distraction content is food-related. In Chapter II, evidence showed a food-specific vulnerability to implicit task-intrinsic distraction in a semantic variant of the recent-probes task. In Chapter III, evidence of a similar vulnerability to explicit task-intrinsic distraction was present in a directed forgetting task, but not a directed ignoring task. Finally, in Chapter IV, evidence of a vulnerability to explicit task-extrinsic distraction in sustained attention was present, but there was no evidence that this vulnerability was exaggerated under food-related conditions. Overall then, our evidence is mixed regarding the food-specificity of cognitive control difficulties associated with obesity. Further complicating interpretation of the results were mixed findings regarding dieting status. Previous research has indicated that eating behaviour patterns such as restrained eating, external eating, and emotional eating, as well as dieting, for example, are associated with a variety of cognitive issues and biases (e.g., Brignell, Griffiths, Bradley, & Mogg, 2009; Brooks, Prince, Stahl, Campbell, & Treasure, 2011; Gearhardt, Treat, Hollingworth, & Corbin, 2012b; Hollitt, Kemps, Tiggemann, Smeets, & Mills, 2010; Hou et al., 2011; Papies, Stroebe, & Aarts, 2009; Tiggemann, 2000; Ward & Mann, 2000). However, despite some indications of dieting-related effects in Chapter II, there were inconsistent effects of dieting in the other studies. We first consider some implications of the effects documented in this dissertation, then the implications of effects that were not reliable and reasons why we might not have been able to detect certain effects. Finally, we turn briefly to a consideration of possible mechanisms underlying our effects, and suggest some directions for future research.

Implications of Significant Findings

In the studies of interference control in working memory reported here, overweight/obese individuals were not globally compromised in their working memory performance, nor were they performing equivalently to their lean peers. Instead, there were specific issues with the control of interference when the content of the task included food. Specifically, in the recent-probes task, there was increased semantic interference from food stimuli, and in the forget task, there was increased proactive interference from food stimuli. These two results are consistent in suggesting that if there is a difficulty in controlling the contents of working memory in individuals who are overweight/obese, it is specific to food. To the extent that the executive control components of working memory are considered exemplars of executive function more generally, these results suggest revisiting previous studies documenting executive function impairment in obese individuals to precisely characterize the nature of those impairments, and to investigate whether those executive function results can be exaggerated in contexts requiring the control of food-related information. These results also show that cognitive control can be altered by stimulus properties and task conditions selectively, as has been demonstrated in other domains or with other types of categories (Berman et al., 2011; Chase & Simon, 1973; Gobet & Simon, 1998; Joormann, Nee, Berman, Jonides, & Gotlib, 2010; Ricks, Turley-Ames, & Wiley, 2007).

However, it is also important to note that the results from Chapters II and III were inconsistent in a sense. In particular, the difference in Chapter II using the recent-probes task was a comparison between lean and overweight/obese participants, while the difference in Chapter III using the forget task was a comparison between conditions within the overweight/obese group. Though we would have initially hypothesized a consistent pattern, even suggesting that we would expect both within- and between-subjects comparisons to produce significant results in each task, there are a number of design differences between the two tasks that may have led to this difference in significant results. In the recent probes experiment, the task had a predictable stimulus structure, with alternating groups of four food and four country names, while in the forget task, two food and two country names were displayed on each trial. Given the results reported here, and other experiments from our lab, we now hypothesize that the four food, four non-food structure may be optimal in an item-recognition working memory task for revealing category-specific cognitive control issues. The predictability of the stimulus order may be leveraged under optimal circumstances to aid in the control of interference, but it seems that if subjects are not able to make use of this predictability and accomplish such leverage, category-specific interference persists. Conversely, when two stimuli of each category are present on each trial, this structure does not offer the same type of predictability to be exploited to facilitate accurate responding. The design involving the display of two stimuli per category also limits the interference scores that can be calculated. With both categories occurring on each trial, it is not possible to calculate semantic and proactive interference separately as we did in the recent-probes task where semantic categories were isolated. Instead, the interference effects in the forget task measured proactive interference, controlling for semantic interference. Given the absence of proactive interference effects in the recent-probes task, it is perhaps not surprising that there were less robust effects in the forget task, although the proactive interference calculations in each task were actually quite different. Altering the forget task to include four stimuli of each category at a time is one potentially interesting future manipulation, permitting the re-assessment of our hypotheses under slightly different task circumstances.

The other predicted result, documented in Chapter IV, was the relative impairment of overweight/obese individuals in sustained attention performance under conditions of distraction. In particular, in the SAT, lean subjects consistently outperformed their peers, but these comparisons became significant in the dSAT condition. Additionally, the effects were of the largest magnitude in the experimental conditions that suggested fatigue may have played a role. Again, though these results were partially consistent with our hypothesis, the results of Experiments 1 and 2 in Chapter IV were statistically inconsistent—the effects were larger and statistically significant only in Experiment 1. As outlined in the discussion of Chapter IV, mental fatigue may have played a role in the strength of the Experiment 1 results relative to the weaker Experiment 2 results. Nonetheless, the pattern of results was qualitatively the same, and statistically there were no interactions across experiments to indicate different patterns. Interestingly, these results occurred in the absence of any specific content—the distraction was strictly perceptual, induced by a screen flashing between black and silver. This highlights the first difference between our working memory and sustained attention results: working memory results revealed impairment in cognitive control only in the category-specific manipulations. In the absence of food information, there were no cognitive control effects. In contrast, the SAT and dSAT have no semantic content, yet control of sustained attention was compromised in our overweight/obese sample when challenged with distraction. This suggests that these two cognitive domains may differ, in that sustained attention appears to be more generally impacted in overweight/obese individuals than working memory.

Implications of Null Results

Though caution is warranted in interpreting null results, several of our inconsistent or absent results merit further consideration. The most obvious is the lack of influence that food stimuli had in the video and image SAT experiments outlined in Chapter IV. There was no indication that overweight/obese individuals were adversely affected by the presence of food information in the distraction presented in those experiments. This may point to one difference between the task-intrinsic experiments and task-extrinsic experiments, or a difference between the working memory and sustained attention domains—either task-extrinsic distraction is not made more salient by the inclusion of food stimuli, or the sustained attention domain may not have category-specific control potential as the working memory system does. A third possibility, of course, is that the tasks we used prohibited the detection of stimulus-specific effects, a point we return to below.

First, however, we should consider the other major inconsistency across chapters in this dissertation, namely, the effect (or lack thereof) of dieting behaviour on performance. Though our initial working memory experiment using the recent-probes task indicated a moderate, negative relationship between dieting and interference control of food information, the subsequent forget task experiment failed to find a relationship. In the sustained attention experiments, there were inconsistent findings—only in the second dSAT experiment were there documented effects of dieting status, and they occurred only in the baseline SAT condition. These results were incompatible with our hypothesis that dieters would show impaired cognitive control when confronted with food information as distraction. The lack of results in the forget task may have been attributable to some of the same task parameter differences outlined above. The results in the sustained attention task were mixed, but it was also surprising to find the only statistically significant difference was in the no distraction condition instead of the more challenging distractor condition. We refrain from interpreting the significant findings related to dieting in the SAT due to their lack of consistency, even numerically, across experiments. Instead we note only that we found more consistent evidence that task-intrinsic and task-extrinsic distractibility are related to overweight/obesity than dieting, but that at least in some contexts, dieting behaviour seems to be an important determinant of cognitive control.

Finally, we found no effect of weight or dieting behaviour in the ignore task in Chapter III. Given the significant effect of weight group documented in the forget task, the null result in the ignore task may indicate that the gating function in working memory is less easily disrupted than the deletion function in working memory. However, it is also true that the ignore task may not be a true test of task-intrinsic distraction in the same way as our other working memory tasks. That is, although the stimuli occur embedded in the task, similar to the recent probes and forget tasks, the to-be-ignored stimuli are identified as such before the memory encoding phase, and are therefore immediately branded as irrelevant. In this sense, the ignore task may be closer to task-extrinsic distraction, which may be completely ignored without being detrimental to performance.

Theoretical Implications

The present results, on the whole, are consistent with some existing theories of obesity as they relate to cognition. Variants of externality theory (e.g., Herman, Polivy, Pliner, Threlkeld, & Munic, 1978; Rodin, 1973; Schachter, 1971; Schachter & Gross, 1968) suggest that obese individuals are more stimulus-bound and responsive to external stimuli, and our distraction results may be interpreted as being consistent with this theory. However, externality theory would likely also have predicted that the image and video SAT experiment would have shown obese or restrained eaters to be more vulnerable to the task manipulations. Additionally, externality theory would also have predicted significant findings in the ignore task. At best, some of our existing results are compatible with variants of externality theory, but our null results also contradict some predictions this theory would make.

To the extent that individuals may overeat as a result of addictive or addiction-related processes, theories of food addiction playing a role in obesity may also be interpreted as consistent with our results. As food acquires increased salience and drive to obtain it intensifies, individuals are likely to be more strongly responsive to food cues (e.g., Berridge, 2007; Field & Cox, 2008; Gearhardt, 2011; Gearhardt & Potenza, 2013; Jansen, 1998; Kroemer et al., 2013; Meule, Lutz, Vögele, & Kübler, 2012). This is consistent with our results showing heightened responses to food distraction in working memory, but is again inconsistent with the sustained attention and ignore task results. Additionally, it is clear that not all individuals who are overweight or obese demonstrate symptoms of food addiction (e.g., see Davis et al., 2011; Gearhardt et al., 2012a), and our sample had relatively few individuals who actually met addiction criteria according to the YFAS, so although some of our results are consistent with behavioural predictions from food addiction theories, a true test of that theory would require a substantially different sample.

Finally, there has been a recent surge in the number of studies assessing response inhibition and obesity, positing that failure to control motor responses is related to failure to refrain from overeating (e.g., Hendrick, Luo, Zhang, & Li, 2011; Meule, Lutz, Vögele, & Kübler, 2014; Mobbs et al., 2011; Nederkoorn, Braet, van Eijs, Tanghe, & Jansen, 2006a; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010; Nederkoorn, Jansen, Mulkens, & Jansen, 2006b; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006c; Volkow, Wang, & Baler, 2011). Although this is an interesting hypothesis, the present results suggest that there are other cognitive control processes involved, as our tasks did not contain motor response inhibition requirements. Further, though the established literature on executive functions being implicated in obesity is not necessarily inconsistent with our results, the specificity of our effects (i.e., effects in the forget but not the ignore task—very closely matched tasks, save for one critical difference) indicates that claims about working memory, executive function, or cognition more globally being involved in obesity need to be investigated more specifically. Previous studies using executive function batteries often rely on tasks that have multiple routes to poor performance, and we suggest that further exploring which mechanisms are responsible for previous documented effects is a necessary step in fully characterising the cognitive correlates of obesity and weight regulation more generally.

. Though obesity was the variable of interest in the experiments reported here, obesity may be a proxy for other physiological or psychological factors, and there may be multiple paths from obesity to changes in cognitive control, or vice versa. Acknowledging that the data presented in this dissertation are not sufficient to draw mechanistic conclusions, we now entertain several possible mechanisms responsible for producing the effects documented in this dissertation. One potential mechanism is that worry and anxiety about weight and shape contribute to heightened prevalence of weight-related thoughts or rumination keeping weight-related thoughts in mind. To the extent that a person worries about weight, shape, dieting, and evaluation on these fronts, food-related thought may be more highly activated in long-term memory, may be more easily allowed into the focus of attention, and may be more difficult to remove from the focus of attention or deactivate in long-term memory, as a result of persistent activation and a plethora of cues causing reactivation. This increased likelihood of activation of food concepts in memory could further bias attention (see Higgs, Robinson, & Lee, 2012; Shaw & Tiggemann, 2004) or make regulation of attention difficult by limiting the availability of executive control resources from working memory. In this case, the mechanism by which weight-regulation-related variables come to influence cognitive performance is psychological. That is, weight has an indirect effect.

One alternative is a more physiological mechanism. There have been studies documenting alterations in the dopaminergic system in obesity (e.g., see Berridge, 1996; 2007; Berridge et al., 2009; Dunn, Kessler, Feurer, & Volkow, 2012; Kessler, 2013; Noble, Noble, & Ritchie, 1994; Wang et al., 2001; Wight, Reid-Westoby, & Davis, 2011), though this work has typically been conducted in animal models. Since dopamine has been implicated in a wide variety of cognitive control, memory, and attention functions (e.g., Braver, Barch, & Cohen, 1999; Li, Lindenberger & Sikström, 2001; Miller & Cohen, 2001; Nieoullon, 2002), one might hypothesize some role of dopaminergic dysregulation in the relationship between obesity and cognition. Recent studies also show relationships between different genetic contributors to dopaminergic function and obesity-related executive function performance (e.g., Ariza et al., 2012) and other studies have linked alterations in the dopaminergic system to conditioning and reward learning issues, and further to response inhibition deficits in humans (Volkow, Wang, Fowler, & Telang, 2008; Volkow et al., 2010; Wang et al., 2001). There is less work linking acetylcholine, a neurotransmitter implicated in successful memory and attention performance, including sustained attention (e.g., Everitt & Robbins, 1997; Sarter & Bruno, 1997), to any alterations in obesity and cognitive functions in humans—most work has focused on various acetylcholine functions in inflammatory and metabolic responses in obesity or cholinergic involvement in hunger and satiety (e.g., Cancello et al., 2012; Das, 2001; Maier, Riedl, Vila, Nowotny, & Wolzt, 2008). Nonetheless, it is possible that acetylcholine is involved in the type of cognitive performance differences we documented here. It is additionally possible that other neurotransmitter systems in the human brain could be altered in obesity, or that interactions between these different systems could contribute to the cognitive effects presented here and elsewhere.

The psychological and physiological explanations outlined above are not mutually exclusive, and could in fact act together to produce the food-specific and the general cognitive control effects reported in this dissertation. One hypothesis might be that since obesity is associated with a number of different psychological and physiological factors, using obesity as the primary variable of interest actually led to the capture of a number of different phenomena. In particular, higher BMI is associated with more restraint and dieting behaviour, and more worry about weight. Perhaps these psychological factors contribute to the food-specific effects displayed in working memory. BMI is also associated with a number of different metabolic and physiological issues, such as high blood pressure and other vascular issues. Since there is evidence of cardiovascular contributions to cognitive function (e.g., Åberg et al., 2009; Dustman et al., 1990; Voss et al., 2011), perhaps these correlates of obesity contributed to the more general cognitive difficulties documented in the present studies.

It is interesting to note as well that the samples of overweight and obese individuals in the current experiments were all young, otherwise healthy, and relatively free of eating-related or other pathology. As time progresses and individuals gain or lose weight, or stay obese for a longer period of time, the profile of physical and psychological correlates of obesity may change, along with the associated cognitive processing. The present results may not generalize well to an older sample of individuals who have been overweight or obese for a longer period of time, or who have developed complications associated with excess weight, such as metabolic syndrome. Finally, since we did not detect group differences in certain kinds of eating behaviour such as emotional and uncontrolled eating in all of our samples, some of our currently lean participants may go on to become overweight or obese. It is therefore possible that the same participants evaluated in the future would show more drastic differences in performance across groups, either food-specifically or generally.

Further, it is possible that each of these explanations has one of multiple possible causal paths. One might suppose that the extent to which an individual is unable to control thoughts about weight and food may lead to weight regulation failure. Some reports also suggest that cognitive difficulties precede weight-regulation issues in children (e.g., Dempsey, Dyehouse, & Schafer, 2011; Francis & Susman, 2009; Parsons, Power, Logan, & Summerbell, 1999; Piché, Fitzpatrick, & Pagani, 2012; Smith, Hay, Campbell, & Trollor, 2011; White, Nicholls, Christie, Cole, & Viner, 2012), suggesting that cognitive effects may precede the development of obesity. However, it could also be that weight gain results in more frequent or intense preoccupying thoughts that then disrupt cognition, or that individuals predisposed to weight regulation issues develop altered cognitive processing as they attempt to control their responses to food. If individuals are predisposed to be more responsive to food cues, such cues may trigger stronger activation of food concepts, resulting in more difficulty controlling food-related cognitive representations. Similarly, biological factors may predispose individuals to weight gain, which then has effects on cognition. Conversely, food overconsumption may cause weight gain, alter reward sensitivity, and influence the dysregulation of some of the biological markers of obesity, such as dopamine neurotransmission and receptor density.

It is also important to note that one need only look at the participant characteristics across our experiments, with each group of participants essentially acquired by sampling the same pool, to see that although all overweight/obese samples share some features, there is variation in eating behaviours and attitudes across samples. Different individuals are overweight for different reasons, and though we attempted to measure and evaluate some of that heterogeneity, it may be that different subgroups of obese individuals carry excess weight for different reasons, further complicating our understanding of mechanisms. Ultimately, however, this dissertation was designed not to determine the mechanisms underlying weight regulation difficulties, but rather to provide proof of concept that distractibility could be a core cognitive correlate of obesity in otherwise healthy adults.

Future Directions

In considering whether the aims were accomplished, it is important to note some limitations on the present results, and to establish some important future directions for subsequent work. First, the set of experiments reported here established some effects of task-intrinsic distraction in working memory and task-extrinsic distraction in sustained attention, but not the reverse. Future research introducing a task-extrinsic distractor in working memory or a task-intrinsic distractor in sustained attention will allow the determination of whether it is the modality or the nature of the distraction that is responsible for the differences between our working memory and sustained attention results.

In the sustained attention domain, refining the task parameters of the image or video SAT to be more demanding and to reduce performance to a level closer to that observed in our initial dSAT experiments would be helpful in more comfortably rejecting the notion that there are food-specific difficulties controlling attention in sustained attention. Additionally, performing a pre- and post-fatigue dSAT experiment to establish experimentally whether or not fatigue plays a role would be helpful in reconciling the results of the first two experiments reported in Chapter IV.

Future work should also exercise more precise control over variables like hunger and craving by manipulating them. Establishing whether the effects documented here are exaggerated when participants have been fasting, or when craving, wanting, or liking are primed before task completion, will be important in determining interactions between these states and the overall state of being overweight/obese versus lean. Further, the present samples were too small to examine interactive effects of dieting behaviour and weight group, or to construct multiple regression models including multiple predictors to disentangle some of the variables that co-occurred with obesity, such as overweight preoccupation, dieting, and restrained eating. Collecting a larger data set would allow the assessment of such interactions, allowing more precise determination of which variables influence performance independently or interactively.

We have restricted our sample to healthy, young adults, who have not reported co-morbid psychiatric or medical conditions. Extending this work into a more diverse population would enable further generalization of the results. To this end, we currently have studies underway to determine the effect of weight loss on cognitive performance among a group of obese individuals who have sought clinical care for their obesity. A counterpoint to this line of research would be to examine cognitive performance in our tasks as predictors of future weight gain or fluctuation over time. If we can assess cognitive performance under this variety of conditions, we should be able to make more nuanced and direct causal claims.

To close, a restatement of the statistics presented in the opening chapter is warranted: more than two thirds of adults in the United States are overweight or obese, while more than one third are obese (Flegal, Carroll, Kit, & Ogden, 2012; Ogden, Carroll, Kit, & Flegal, 2012). Additionally, only about 20% of overweight individuals are able to maintain at least a 10% weight loss for at least 1 year (Wing & Phelan, 2005). Without placing a value judgment on leanness, or endorsing the substantial bias and prejudice that exist toward overweight and obese individuals (e.g., Carr & Friedman, 2005; Crandall et al., 2001; Hansson, Karnehed, Tynelius, & Rasmussen, 2009), the fact remains that many individuals are overweight or obese, and many individuals seek unsuccessfully to lose weight (see also Brownell & Rodin, 1994). Perhaps if the cognitive effects associated with obesity can be more completely understood, we will be able to apply cognitive training interventions to weight loss programs to augment the existing interventions. If we can reduce the psychological contributions to hampered cognitive performance in obesity, and if we can reduce the cognitive contributions to excess weight maintenance through intervention, perhaps we can improve the personal self-efficacy of individuals seeking to lose weight, and improve the overall efficacy of the weight-loss regimens on which they embark.

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Appendix A

Stimuli Used in Recent Probes, Forget, and Ignore Tasks

(Chapters II and III)

Country Stimuli (Recent Probes, Forget, Ignore Tasks)	Country Stimuli (Forget, Ignore Tasks)	Food Stimuli (Recent Probes, Forget, Ignore Tasks)	Food Stimuli (Forget, Ignore Tasks)
Austria	Aruba	Bacon	Apple
Belgium	Australia	Brownie	Bagel
Brazil	Bahamas	Burrito	Batter
Canada	Belize	Butter	Biscuit
China	Ecuador	Caramel	Candy
Cuba	Fiji	Cheese	Cereal
Denmark	Germany	Chips	Cheddar
Egypt	Ghana	Cookie	Cobbler
England	Haiti	Cupcake	Cream
Finland	Hungary	Donut	Crepes
France	Iceland	Fries	Custard
Greece	Iraq	Fudge	Fish
India	Israel	Gravy	Fruit
Ireland	Jamaica	Burger	Granola
Italy	Jordan	Lollipop	Kiwi
Japan	Korea	Licorice	Lasagna
Kenya	Kuwait	Muffin	Noodle
Mexico	Monaco	Pancake	Pastry
Norway	Nepal	Pasta	Peanut
Peru	Pakistan	Pizza	Pretzel
Russia	Poland	Popsicle	Salsa
Spain	Syria	Sausage	Spaghetti
Sudan	Taiwan	Tart	Taco
Sweden	Thailand	Toffee	Wafers
Yemen	Ukraine	Waffle	Yogurt