The Associations between Body Weight and Executive Function

by

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Abstract

Executive functions are high level cognitive mechanisms that manage everyday thinking and behaviour. Miyake et al's (2000) model separates executive function into three fundamental elements: shifting, inhibition and updating. Initially, a Systematic Review examined twenty-two papers. Most studies reported poorer executive function in obese individuals in clinical settings but there was a lack of work in community populations.

Study One examined the relationship between executive function and weight in 315 community–based individuals who completed a cognitive test battery testing shifting (Local-Global task), inhibition (Stroop task), updating (Keep-Track task), and a complex task (Random Number Generator). Body Mass Index (BMI) was calculated according to standard World Health Organisation (WHO) criteria. Self-reported depression, demographic and clinical variables were obtained. Quantile regressions, ANOVA and correlations revealed clear differences between the BMI categories across the cognitive tests with underperformance on tests of inhibition, shifting and updating in both obese class III and underweight categories.

Study Two examined the relationship between the performance-based cognitive tests employed in Study One and the self-report Behaviour Rating Inventory of Executive Function (BRIEF-A), to aid understanding of how deficits may impact individuals in their everyday life. A separate cohort of 400 community participants were recruited. Using quantile regression analysis, Study One results were not fully replicated in Study Two. Some limited differences were noted, with overweight and obese individuals underperforming in updating tasks in comparison to normal weight and underweight individuals. No associations between the BRIEF-A and cognitive tests were observed.

To conclude, there is some evidence to suggest that there is a link between weight and executive function but there were inconsistencies between the studies. The discussion highlights the need for further work to examine the reasons for these inconsistent effects.

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Prelude

Chapter 1. Weight and its Consequences

This chapter presents an overview of weight and the impact it has on the general population of the United Kingdom with a specific focus on obesity and its worldwide impact. The physical health consequences of obesity are considered and attention given to diabetes, hypertension and cardiovascular disease, often associated with elevated weight. The cognitive consequences of obesity and an outline of cognition are discussed, outlining different cognitive functions, including memory, attention and executive function, which are associated with obesity. The relationship between obesity and Alzheimer's Disease and depression are also examined. The chapter then provides an overview of eating behaviours and the relationship between underweight individuals and physical health and cognitive consequences.

Chapter 2. Executive Function: Definition, Theory and Measurement

This chapter examines the area of cognition known as executive function. It provides an outline of the definitions that research groups have used to describe executive function and the difficulties of having numerous explanations of this concept. An examination of the theory of executive function is provided with detail on the multi-store model (Atkinson & Shiffrin, 1968) and multi-component model (Baddeley, 1986; 2010) culminating in the framework of executive function provided by Miyake, Friedman, Emerson, Witzki and Howerter (2000). This framework provides a definition of executive function driven by three functions: updating, shifting and inhibition which are outlined and summarised. The chapter concludes with a discussion of the different ways to assess and measure for the functions with detailed descriptions of the tasks.

Chapter 3. A Systematic Review of Obesity and Executive Function

This chapter examines the relationship between weight and executive function by systematically reviewing twenty-two studies, chosen via inclusion and exclusion criteria. Evidence of the relationships between weight and the three executive functions; updating, shifting and inhibition with insights into the relevant performance based cognitive tests is reviewed. The relationship between normal weight, overweight and obese weight groups as well the type of assessment and measures in particular is examined. The chapter concludes with a discussion of the unclear relationship between weight and executive functions which warrants further attention. The consideration of the potential reasons for the inconsistency of findings in the literature are reviewed. This chapter highlights the lack of evidence exploring all three of the executive functions, lack of underweight work, a small number of studies controlling for a range of variables and minimal studies incorporating both self-report and performance-based test.

Chapter 4. Study 1

Introduction. This section presents the rationale for conducting a study aimed at evaluating weight and executive function in a community setting. Clinical studies with older populations researching this area of cognition and health dominate the field with limited work focussed on the working-aged community population. Potential confounders such as gender and depression are explored and the importance of controlling for them is highlighted. Research to include all the body mass index (BMI) groups, inclusive of underweight individuals, is also emphasised.

Methods. The methods used to recruit three hundred and fifteen individuals from a community population are discussed. A recruitment process was adopted for each of the populations: business, community centre and student. This details how the access to potential participants was granted and the recruitment strategies at each site. Methods for the collection of clinical, demographics and self-reported methodologies (Center for Epidemiological Studies Depression Scale: CES-D; Radloff, 1977) are presented. Methods for the collection of weight and height measures are also presented. The performance-based cognitive tests are detailed with an overview of each task, the justification for the choice of task, the materials required to carry out each task and the standardised procedure for each task.

Results. Data was obtained for 315 individuals and analysis of this data and key findings are presented. The rationale for the use of the quantile regression statistics is presented. All six BMI groups were represented: underweight (n= 39), normal weight (n= 108), overweight (n= 57), class I obesity (n= 53), class II obesity (n= 30), class III obesity (n= 28). Differences were found across all four of the tests of executive functions. Differences were noted between the genders and across the three quartiles: lower, median and upper. Summaries of results and an explanation of outcomes for each of the cognitive tests are presented.

Chapter 5. Study 2

Introduction. This section presents the rationale for conducting a study aimed at evaluating the relationship between weight and executive function using performance-based and self-report methodologies. The use of them to measure executive function is discussed and evidence is shared which highlights that it is unclear whether performance-based and self-report measure the same aspects of executive function or not. In studies of executive function and weight very few have included both performance-based and self-report measures. This section includes the rationale of the need for research which accounts for the impact of executive functions in everyday life. The importance of trying to replicate the findings from Study One is highlighted.

Methods. The methodological approach used in this study followed the previous study design. Additional methods are discussed in this section. The collection of self-reported measures for depression (Patient Health Questionnaire -8: PHQ-8; Spitzer, Kroenke & Williams, 1999), sleep quality (The Pittsburgh Sleep Quality Index: PSQI; Buysee, 1988) and loneliness (UCLA Three item Loneliness Scale; Hughes et al., 2004) are detailed.

Results. Data was obtained for 400 participants and analysis of this data and key findings are presented. From the community population all six BMI groups were represented: underweight (n= 83), normal weight (n= 87), overweight (n= 65), obese class I (n= 81), obese class II (n= 58), obese class III (n= 26). Few differences were found across the BMI groups for each of the cognitive tasks. No differences were found across the weight groups and the BRIEF-A scales. The relationship between the BRIEF-A and the cognitive tests could not be determined. This section also details the outcomes of the loneliness and sleep quality self-report measures.

Chapter 6. General Discussion.

This chapter examines the outcomes of the systematic review and both studies in the thesis. Results from the Study One and Study Two are summarised and the key findings discussed. It is suggested that there are potentially executive functions differences between the weight groups and the differences between the groups are offered to explain this. The unique contribution that the results have to the literature is explored with a focus on community-based studies and the collection of data across the BMI spectrum, from underweight to obese class III. The association between behavioural cognitive tests and self-report tests which both assess for executive function are also considered. Strengths and limitations of the study methodology are examined. The association between weight and executive function is complex. The reasons for inconsistencies in the findings of the empirical work will be the focus of future research.

Chapter 1. Weight and Consequences

1.1. Obesity and the general population

The increasing prevalence of obesity is a global issue and a major contributor to worldwide chronic disease. Obesity is defined as abnormal or excess fat accumulation to such an extent that health may become impaired (World Health Organization, 2003). Over the last four decades, there has been a global increase in the incidence of obesity, with obesity now classified as one of the most common nutritional disorders. The most commonly used measurement to define obesity at a population level is Body Mass Index (BMI), a measure of weight for height calculated as weight in kilograms divided by height in metres squared (kg/m^2). The World Health Organization (WHO) has identified classifications of BMI related to the levels of underweight, and overweight or excess weight with cut off points identified as $25kg/m^2$ for overweight and $30kg/m^2$ for obesity, the point at which the risk of ill health related to weight rises exponentially (WHO, 2000). The obesity classification is split into three further levels of obesity (Table 1). The cut off points identify the degrees to which excessive weight is associated with the increased risk of physical consequences and have directly led to higher mortality in many populations (WHO, 2000). Currently in England, more than 6 in 10 adults are overweight or obese: 67% of men and 60% of women. Specifically, 26% of men and 29% of women were classified as obese with 2% of men and 4% of women classified as morbidly obese. The average adult BMI values stand at $27.5kg/m^2$ for both men and women (Public Heath England: Health Survey for England, 2019).

Table 1 – WHO BMI Classifications

Classification		BMI (kg/m^2)
	Underweight	< 18.5
	Normal weight	18.5 - 24.9
	Overweight	25.0 - 29.9
Obese	Class I Obesity	30.0 – 34.9
	Class II Obesity	35.0 – 39.9
Morbidly Obese	Class III Obesity	≥ 40.0

To provide a better understanding of obesity an additional measure is regularly used, the National Institute for Health and Clinical Excellence (NICE) has recommended the use of a waist circumference measurement in addition to BMI to provide an indication of total body fat (NICE, 2014). BMI is not a measure of central abdominal obesity which has often been associated with increased obesity health risks. It cannot account for the proportions of fat and lean tissue in several different body shapes and cannot be used to identify where fat is located. In collaboration with BMI, waist circumference calculations (Table 2) account for these risks and provide a better picture of the impact of excessive weight (Lean et al., 1995).

Table 2 - Combined recommendations of body mass index and waist circumference cut-off points and association with disease risk (NICE, 2015)

Classification	BMI (kg/m^2)	Waist circumference (cm)	
	Men:	94-102	>102
	Women:	80-88	>88
Underweight	< 18.5	No increased risk	No increased risk
Healthy weight	15.-24.9	No increased risk	Increased risk
Overweight	25-29.9	Increased risk	High risk
Obesity	>30	High risk	Very high risk

It is important that the ability to accurately monitor weight is available in the fight to understand and control global obesity. Excessive weight can result in serious health concerns, both physical and mental in nature, which are potentially life threatening.

1.2. Physical Health Consequences

Excessive body weight can lead to the body being impacted in a negative way and this can result in a number of physical consequences and the risk of chronic health conditions and diseases including; type 2 diabetes, hypertension, cardiovascular disease and forms of cancers (Hauner et al., 2016; Qiu et al., 2005; Jiang et al., 2016; Poirier & Eckel, 2002; Jauch-Chara et al., 2011).

In 2018, Cancer Research UK, engaged the public using mass advertisements to ask the question “Guess what is the biggest preventable cause of cancer after smoking” with the simple aim of making the public aware of how obesity can be an attributing factor to this often life-threatening disease. Cancer, when abnormal cells divide in an uncontrolled way, will affect 1 in 2 people in the UK and is globally the second leading cause of death, with 1 in 6 deaths due to cancer (WHO, 2018). Currently in the UK overweight and obesity accounts for 6.3% of cancer cases, 7.5 % in women and 5.2% in men (Brown et al., 2018). With cancer incidence expected to rise it is understandable that initiatives are focussing on weight management as a way to control for the bodily effects of excess fat. Further to this in 2018/19 in England, 11,117 hospital admissions were directly attributable to obesity with a further 874,000 admissions where obesity was a key factor, an increase of 23% from 2017/18 (NHS Digital, 2020).

1.2.1. Diabetes

Excessive weight is an established risk factor for type 2 diabetes (Nguyen et al., 2011). Physiologically obesity has been shown to disrupt the body's metabolism in many ways; in particular, an excessive amount of abdominal fat is a marker for excess visceral adipose tissue. By-products of this tissue cause the body to be less sensitive to the insulin it produces by disrupting the function of insulin responsive cells, resulting in raised glucose levels (hyperglycaemia) (Hauner et al., 2016).

The Nurses Health Studies (Hruby et al., 2016) reviewed studies of three cohorts of American women aged 30-55 from 1976 to 2016 to provide a narrative overview of the determinants and consequences of obesity. Across the data they found that the risk of type 2 diabetes in women with a BMI above 35 was higher than those with a BMI below 22. They established that weight gain was a strong risk factor for developing type 2 diabetes. In a recent 2020 review, Piché and colleagues further examined the relationship between diabetes and obesity and showed that the clear association between type 2 diabetes and the obesity pandemic accounts for the high prevalence of type 2 diabetes which is seen in many countries. They also go onto suggest that obesity is often linked to hypertension, with many high-risk obese individuals characterised by metabolic and cardiovascular risk factors.

1.2.2. Hypertension and Cardiovascular Disease

Obesity and related metabolic conditions such as type 2 diabetes are known to negatively impact the cardiovascular system. Those individuals classified as obese are more likely to develop cardiovascular disease and manifestations of cardiovascular disease (Piché et al., 2020). Poirier et al. (2006) raised the importance of weight management following their update of the American Heart Association Scientific Statement on Obesity and Heart Disease where they reviewed the evidence of the impact obesity has on cardiovascular disease. There was evidence that obesity is an independent risk factor for cardiovascular disease (Poirier & Eckel, 2002).

In support of this, in a review of obesity and hypertension, Jiang et al. (2007) concluded that there is no single cause to explain all the cases of obesity worldwide but there was much evidence to suggest that obesity can cause cardiovascular disease through a number of mechanisms including, dyslipidemia, an abnormal lipid (cholesterol profile, comprising high triglyceride levels, low high-density lipoprotein (LDL) and high low-density lipoprotein (LDL) (Tuck et al. 2000) and hypertension, defined as a systolic blood pressure (SBP) of 140 mmHg or more and a diastolic blood pressure (DBP) of 90 mmHg or more (NICE, 2019). A number of these disorders can occur at the same time and are often noted in the presence of excess fat which can cause increased lipid accumulation and negatively impact metabolic syndrome. Metabolic syndrome is a cluster of conditions which increases the risk of coronary heart disease, stroke and other vascular diseases. Conditions which increase risk include diabetes, abdominal obesity, high cholesterol and high blood pressure (Alberti et al., 2005).

With so many associations between obesity and potential risk factors, it is important to control for these when carrying out research to account for possible confounds. The physical ramifications of excessive weight are not the only way an individual's health can be impacted. Copious amounts of research have shown the physical consequences of obesity but psychological consequences can be equally impactful.

1.3. Cognitive consequences of obesity

As the physical consequences of obesity become well established, focus has moved to explore the association of cognitive function with obesity. This was the logical next step, as poor cognition has often found to be associated with diabetes, hypertension, cardiovascular disease and the metabolic syndrome (Yates et al, 2012). Cognitive functioning refers to a range of mental abilities, including thinking, reasoning, problem solving, learning, remembering, decision making, and attention (Baddeley, 2010). Over the past two decades there has been much interest between the association of obesity and cognition.

In 2003, Elias and colleagues presented data using the Framingham Heart Study, an ongoing longitudinal project involving over 5000 Framingham residents which predominantly identifies the common characteristics or factors which influence cardiovascular disease. Using this large population sample, the research team were able to use a sample free from cardiovascular disease, clinical stroke and dementia to examine the effect of obesity and hypertension on cognitive function. Obesity and hypertension are known independent risk factors for cardiovascular disease and Elias et al. hypothesised that this independence would be reflected in cognitive performance. The Kaplan– Albert Neuropsychological Test Battery was utilised and presented eight subtests. The subtests measured performance on long-term visual memory, verbal learning, visual organisation, visual memory, attention and concentration, abstract reasoning and concept formation.

Analysing the data from the neuropsychological test battery on 1423 participants, classified into normal weight, overweight and obese groups they found a significant independent association for both obesity and hypertension on cognition tests of learning and memory, adding that the observed cognitive effects were noted for men but not for women. They concluded that overall obesity was associated with lower cognitive functioning in middle-aged and elderly men and this association remained when common cardiovascular risk factors were controlled for.

Further evidence for the association between obesity and cognition comes from a three-year follow-up after bariatric surgery study (Alosco et al., 2014). Bariatric surgery continues to be an effective treatment for weight loss in obese individuals, with the loss of weight associated with lower mortality risk (Wiggins et al., 2020). Data was assessed for 50 bariatric patients participating in the Longitudinal Assessment of Bariatric Surgery projects. Patients completed a battery of cognitive behavioural tests to assess executive function (explored further in Chapter 2) at 12 weeks and then 12, 24 and 36 months post bariatric surgery. The tests assessed attention and executive function utilising a digit span task, and adaptations of the Trail Making Test, the Stroop Colour Word Test and the Austin Maze test. Prior to the bariatric surgery on average patients were classified as very severely obese at baseline (Mean BMI = 46.61 kg/m^2) whilst the average reduced to a moderately obese status at the 36 month post-surgery time point (Mean BMI = 32.35 kg/m^2).

The group hypothesised that cognitive function would improve post-surgery and found significant improvements in attention, executive function, and memory. Cognitive improvements reached their peak at 36 months in executive functions with short term improvements in memory maintained at 36 months. The team went on to conduct exploratory analysis at follow-up visits up to 48 months and it indicated that these cognitive benefits still exist. This study shows the cognitive benefits of bariatric surgery and that reduced weight can positively impact cognition in the long-term.

In a further study, Benito-León et al. (2013) analysed data from over 5000 elderly participants taking part in the Neurological Diseases in Central Spain study. Overweight (n = 850) and obese (n = 592) participants performed poorer on the neuropsychological tests compared to the normal weight (n = 507) participants, even when adjusting for potential confounds including age, gender, diabetes and hypertension. These results provide further evidence that there is an independent association between having an elevated body mass index and cognitive test performance.

This positive association was not found in the community sample which Gonzales et al. (2010) utilised. Using functional magnetic reasoning imaging, this research team were interested in detecting early changes in brain response to cognitive challenges. They administered tests accounting for memory, executive function, emotional function and global cognition (including the Wechsler Adult Intelligence Scale III, Digit Span Subtest; Controlled Oral Word Association Test; Trail Making Test A&B) on normal weight (Mean BMI = 22.4 kg/m^2), overweight (Mean BMI = 27.4 kg/m^2) and obese weight groups (Mean BMI = 34.3 kg/m^2). A large number of exclusions included metabolic disorders, coronary heart and neurological disease, with participants matched to include age and years of education. This study revealed no significant differences across the three weight groups for all of the tests of cognition. It has to be considered that this study used only a small sample (N=32) but also that the population was not from a clinical or bariatric sample which was usually the case for these types of studies.

Smith et al (2011) provides a review of the association between obesity and cognitive function across the lifespan exploring thirty-eight cross-sectional and prospective studies covering an age range from 4 years to 95 years. They found that studies on obesity and cognition in children, adolescents and adults provide evidence that obesity is associated with cognitive deficits and were independent of depression, socioeconomic status and cardiovascular considerations. When evaluating the studies, they noted that obesity collectively impacted cognitive function but there were certain areas of cognition which were more consistently associated with decline, especially for measures of executive function. However, much of the cognitive function and obesity research has been analysed retrospectively and has come from larger project databases spanning back decades; this has resulted in elderly populations being over-represented in the data. These datasets provide a wealth of data but cannot account for the working age individuals where difficulties in cognitive function may be most detrimental.

1.4. Obesity and Alzheimer's Disease

Evidence that obesity adversely affects the central nervous system and has associations with cognitive function has been accumulating. There are also strong associations between obesity and dementia, especially Alzheimer's disease, a specific degenerative brain disease whereby cellular changes lead to the death of nerve cells and memory failure (Alzheimer's Society, 2014). Dementia describes progressive neurological disorders, conditions that affect the brain and is a general term for decline in mental ability severe enough to interfere with daily life (Dementia UK, 2020). The Alzheimer's Society (2014) reports that in the UK there are over 850,000 people living with dementia with the risk of an individual developing dementia increasing with age. In the UK it is estimated that the number of people living with dementia by 2021 will rise to over one million. It is unsurprising therefore that research has focussed on the association between obesity and Alzheimer's disease, two major health problems.

Gustafson et al (2003) carried out an 18-year follow-up of 392 Swedish individuals to assess the relationship between BMI and dementia, diagnosed by a psychiatric examination, hypothesising that those individuals classified as overweight would have an increased risk of dementia. The findings suggested that being older and overweight is a risk factor for dementia, especially Alzheimer's disease, and this risk was more likely in women. In elderly white women, there was a relationship between being overweight or obese at 70 years and the development of Alzheimer's disease 10 to 18 years later. There was increased dementia risk associated with being overweight, with BMI being 3.6 higher in those who developed Alzheimer's disease compared to those who did not. This relationship remained after a number of potential confounds including cardiovascular disease, stroke, diabetes mellitus, cancer and later-life depression were considered.

However, in recent years it has been suggested that overweight and obesity reduces the risk of dementia and could increase survival compared with normal weight individuals (Pedditizi et al., 2016; Wang et al., 2016). In a 2019 systematic review and meta-analysis, Danat and colleagues examined the impacts of overweight and obesity in older age individuals and the risk of dementia. They assessed 16 studies and found no evidence of the positive impact of overweight and obesity on the incidence of dementia. Overall, the influence of weight remained unclear with limited evidence to show that a weight loss intervention would reduce dementia directly. The data indicates that the effects of overweight and obesity on dementia may be due to other conditions such as diabetes which are closely related to incident, newly diagnosed, dementia. Therefore, controlling bodyweight can prevent incident dementia but may be related to the physical consequences rather than obesity alone.

Studies have recognised that a potential first step in incident dementia can be highlighted by poor cognitive function via performance-based tests (Darweesh et al., 2017; Brenowitz et al., 2020). Therefore, tests utilising this methodology on an obese population may act as the preliminary work.

1.5. Obesity and Depression

Another area of ongoing interest is the association between depression and obesity. Depression is a common mental disorder with more than 264 million people affected worldwide. It is a broad and heterogenous diagnosis, characterised by low mood and/or loss of pleasure in daily activities (NICE, 2009). It is a serious health concern and is the leading cause of disability globally. Screened and defined through self-report methodologies such as questionnaire (e.g Patient Health Questionnaire – 9; Spitzer, Kroenke & Williams, 1999) or through interview based psychiatric diagnosis, it is considered a major contributor of the overall burden of disease globally (WHO, 2020).

With both obesity and depression burdening society in such a colossal way, researchers over the years have been interested in the associations between the two conditions with a number of studies having examined this relationship. In 2010, Luppino et al. reviewed seventeen studies in a meta-analysis of the general population with a total of 204, 507 participants. They found a significant association between the two variables, even when potential moderators such as age and the methodology used to define depression were considered. Gender differences influenced this association, with depression and obesity more evident in females than in males.

A review by Faith et al. (2011) went on to further investigate the relationship and directionality by examining 25 studies testing 'obesity-to-depression' and 'depression-to-obesity' pathways. They concluded that the relationship between depression and obesity was bidirectional, if one condition is present the risk of developing the other is increased. In total, 80% of studies found support for significant obesity-to-depression pathways, while only 53% found significant evidence for depression-to obesity associations.

This is further supported by Milaneschi et al. (2019). They recognised that obesity and depression are both closely related and that an interaction between the two conditions exists and can cause a persons' health status to decline. It was noted that they share mechanisms including biological pathways which map onto both depression and excessive body weight and is an explanation for their co-occurrence within individuals. These shared mechanisms, which can cause biological alterations, such as increased inflammatory activation and changes in the insulin pathway which regulates glucose metabolism, had the potential to influence the central nervous system regulatory processes and brain mechanisms. With these links having been made it is important that any further research into obesity considers the potential impact which depression may have on results and associations between variables.

1.6. Underweight

Associations between having an elevated weight and both physical and cognitive consequences have been found. With the impact that this has had on clinical and hospital services it is unsurprising that work over the past decade has focused on obesity. Obesity, especially the upper BMI classes, can often be described as an extreme weight condition but the relationship between weight and ill health is not just limited to the upper end of the scale. Underweight individuals (BMI < 18.5kg) can also be at risk, with low weight linked to nutritional deficiencies, a weakened immune system and fertility problems (NHS Digital, 2020). An underweight BMI can be linked to the eating disorders Anorexia Nervosa and Bulimia Nervosa and it is also known to affect older people (Gants, 1997).

Some comparisons have been made between the underweight and other BMI weight classes to establish the similarities and differences. Kelly, Lilley, and Leonardi-Bee (2010), using data from 10, 243 community-living residents from the Health Survey for England (2003) looked to establish whether or not underweight data could be used when estimating the health and mortality impacts of BMI. Using this comprehensive dataset they were able to analyse a number of demographics (gender, age), health behaviours (cigarette consumption, work activity level, walking activity level) illnesses (hypertension, cardiovascular disease, diabetes) and biochemical measures (cholesterol, C-reactive protein). Overall, they concluded that the underweight class was not significantly less healthy than all of the weight groups with a surprising lack of differences found between the underweight and healthy weight groups. This cross-sectional population does not account for individuals in institutionalised settings but provides an indication from a community standpoint.

The underweight population can often be overlooked in research examining weight and cognition. Sabia et al. (2009) looked to remedy this by targeting all BMI groups over the adult life course when assessing cognition in late midlife, aiming to identify whether weight over a lifetime is associated with later cognitive function. Data from the Whitehall II Cohort Study (n= 10,308) was used, along with a battery of five cognitive tests to assess cognition: Mini Mental State Examination (MMSE), Free Recall Test, The Alice Heim 4-I (3 test; AH4-I). The results from this study suggested that long term obesity and long term underweight were both associated with lower cognitive performance in late midlife. Whereas Kelly et al's study (2010), looking into health factors, showed little differences between the groups on a cognitive level, with similar results being found at either end of the BMI weight classes. The underweight population should not be discounted from research accounting for the health or cognitive associations of weight.

1.7. Eating behaviours

Underweight individuals are often associated with eating disorders. Eating behaviours can be disturbed and can lead to the altered intake of food which can ultimately have a negative impact on health and psychosocial functioning (NICE, 2019). This can range from disorders which are associated with obesity such as binge-eating, where an individual may eat an amount of food over a discrete period of time that is larger than what most people would eat in a similar period of time or the feeling that they cannot stop eating or control what they are eating (APA, 2013). To behaviours which are associated with underweight groups such as anorexia nervosa. Those diagnosed with bulimia nervosa exhibiting binge-eating behaviours followed by inappropriate compensatory behaviours to prevent weight gain, such as self-induced vomiting; misuse of laxatives; fasting; or excessive exercise (APA, 2013). The diagnostic criteria for anorexia nervosa includes the restriction of energy intake which will lead to a significantly low body weight with a fear of gaining weight or persistent behaviours that interferes with weight gain (APA, 2013).

These groups have been found to be cognitively impaired. Both anorexia nervosa and bulimia nervosa groups have been found to perform worse on tests of cognitive functions compared to health controls (Hirst et al., 2017). This includes dysfunctions across different processes and functions. Wu et al. (2014) analysed 64 studies with a focus on set-shifting and found that studies strongly supported impairments in those with eating disorders. Guillaume et al. (2015), whilst assessing 23 studies found that the performance on a test of decision-making was significantly worse when an individual had been diagnosed with an eating disorder. Results such as these highlight the potential that certain cognitive dysfunctions could be related to maladaptive eating behaviours. Although results are not all consistent, Bartholdy et al. (2015) reviewed 62 studies and found that some of the studies which accounted for inhibition found no impairments between those with and without an eating disorder. The inconsistent links with cognition and those who are underweight as well as the association with disordered eating emphasises how important it is to look at cognition across a wide range of weight classifications, and if possible, disorders.

1.8. Conclusion

Overall, the literature has suggested the importance of the physical and cognitive consequences associated with obesity. As implied by much of the research the relationship between weight and the consequences is bi-directional but there is a strong sense that excessive weight is detrimental to both the body and the mind. The physical effects can be tracked more easily than cognitive effects. Given the strong links to depression and dementia, it is important that these cognitive functions are better understood, especially in relation to executive function. Furthermore, it is important to consider all of the BMI weight groups, including the underweight class to provide a complete picture for any potential associations. This thesis aims to explore the relationship between body weight and executive function.

Chapter 2. Executive Function: Definition, Theory and Measurement

2.1. Definition

Executive function is a construct which has been so hard to define that there exists no sole universal definition. Although not clearly defined there is a consensus that it is of critical importance for development and is linked to learning, attention and memory. It is generally considered to be cognitive processes that help us to regulate, control and manage our thoughts and actions. Initial interest in executive function began when effects were seen in those with frontal lobe damage with the beginnings of executive research mostly derived from neuropsychological research (Luria, 1966).

Executive function is multidimensional, there are a number of different models, frameworks and thoughts providing a range of perspectives (Banich, 2009). The executive functions have been born from a number of different processes in which a definition needs to provide the collective understanding of cognitive regulation, behavioural regulation and emotional regulation. In Goldstein and Naglieri's 'Handbook of Executive Functioning' (2014) over twenty definitions of executive function were reviewed. Examples of frameworks include the information processing approach (Butterfield and Belmont, 1977; Borkowski & Burke, 1996) where executive function was seen as a necessary process for academic achievements, successful learning, self-image, and future-orientated thoughts and goals. This view on executive function coordinates the ability to monitor and control knowledge and strategies, metacognition and the knowledge and conscious awareness of those skills and strategies. A neuropsychological standpoint includes the work by Welsh and Pennington (1988) who defined executive function as the ability to maintain an appropriate problem-solving set, in order to reach and complete a goal using several mechanisms including planning and inhibition.

A number of theories will define executive function in relation to the individuals which they are attempting to identify with i.e. children, patients, students. There is a lot of overlap of the main elements of executive function but with each theory comes additional components setting them apart. In the past it was suggested that a lack of progress in executive function research was due to the failure in establishing a shared meaning (Borkowski & Burke, 1996). There is a lot of evidence which could be streamlined to better represent executive function. It is not necessarily that they disagree but with widespread definitions it becomes difficult to measure. Overall, there have been difficulties with finding a consensus on a general definition which in turn has made it challenging to appropriately measure executive function and generalise research conclusions.

In recent years there has been a movement towards a definition of executive function encompassing a number of processes and abilities which allows for better measurement and provides a clear guide. Delis (2012) noted that not a single ability or a comprehensive definition would be able to capture the scope of the executive functions, believing that the best way to approach the concept was to see it as a collection of higher-level skills which help an individual to adapt and thrive. To fully appreciate the role of executive function we have to understand the theoretical origin. These models will be explored in further detail and have stemmed from cognitive theory.

2.2. Theoretical Models

Very consistent in the literature is the association between executive function and working memory, the processes that allow us to hold on to and manipulate information we are currently aware of and working on. Working memory is responsible for keeping things in mind while performing complex tasks such as learning and reasoning (Baddeley, 2010). The base theory for executive function has often stemmed from working memory and the role of the central executive within these theories have become the starting point in understanding this construct.

The multi-store model proposed by Atkinson and Shiffrin (1968) consists of three stores: sensory memory, short-term memory and long-term memory. The model assumes that environmental stimuli receive attention from the sensory system and then enters the short-term memory store. This store, the working memory role, actively controls the information which goes in and out of the long-term memory store. This occurs via the maintenance rehearsal of sensory memory, the repetition of information in short-term memory and then this information is recoded and stored in long-term memory. This model puts much emphasis on the short-term memory store and it has been suggested that this plays a large part in cognitive tasks and learning which are heavily associated with executive function (Atkinson & Shiffrin, 1968). It is widely known that the multi-store model is limited in that it cannot explain for those patients who show dysfunctions in short-term memory through brain impairment but are able to form long-term memories (Shallice & Warrington,1970). In line with this model, if an impairment occurs in the short-term then one would not be able to maintain the information long enough to be moved and stored in the long-term. This unitary model has difficulties in addressing the separate differences between the short-term and long-term memory stores.

The multi-component model proposed by Baddeley (1986; 2010) is a dedicated system which is accountable for maintaining and storing information in the short-term, and this system is crucial in mediating human thought processes. The system is headed by a central executive which acts as a supervisory system responsible for the regulation of cognitive processes via the coordination of the two ‘slave’ systems; the visuospatial sketchpad which processes visuo-spatial sequences and the phonological loop which processes verbal sequences (Figure 1). Both systems provide short-term storage which is limited in its capacity. The visuo-spatial sketchpad is responsible for maintaining and manipulating visual images but only has the capacity to hold two or three objects. Likewise, the phonological loop, responsible for maintaining and manipulating verbal information, can only hold memory traces for up to three seconds (Baddeley, 2010). In addition to this, Baddeley (2000) added one more ‘slave’ system to the multi-component model, the episodic buffer. The episodic buffer integrates the visual, spatial, and verbal information from the other ‘slave’ systems and information from episodic long-term memory which allows for unitary episodic representation. The episodic buffer is assumed to be controlled by the central executive, which is responsible for combining information from many sources to provide coherent episodes.

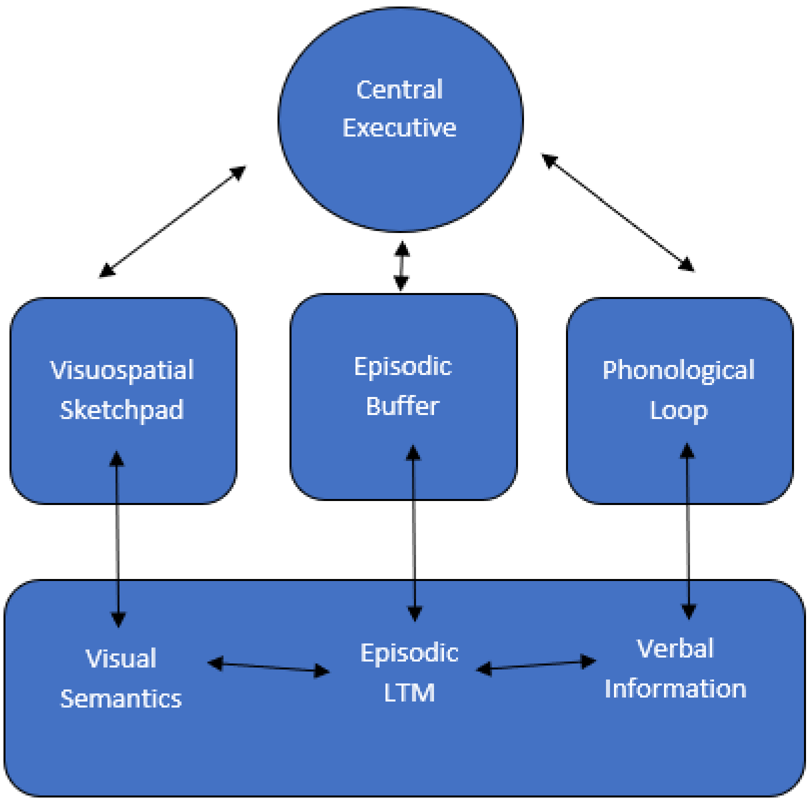

Figure 1 - Baddeley’s (1986; 2010) multi-component model of working memory

The above theories of working memory have become integral to executive function theory due to the inclusion and introduction of the role of the central executive which mirrors the executive functions. Baddeley's (1986; 2000) multi-component model suggests that subsystems of working memory and each of these systems control different characteristics of human thought, emotion and behaviour. While working memory is theorised to be split into these systems, no subfunctions are identified for the central executive, it is assumed to be unitary. However, as suggested from approaches and recent definitions, there is evidence that the central executive or executive function is made up of multiple functions and abilities. Evidence from clinical observations suggests that on tests of executive function there are differences in performance among the executive tasks. If executive function was a completely unitary system then it would be expected that if patients have a dysfunction that they would fail on all tests of executive functions. However, it was found that some patients would fail on one test of executive function but not another, indicating that executive functions may not be completely unitary (Godefroy et al, 1999; McKinlay et al., 2010). This viewpoint is also supported by individual difference studies which highlighted dissociations in performance on executive function tasks (Friedman et al., 2011; Rose et al., 2011) with one set of theorists providing a framework to approach executive function as both a unitary and diverse system.

With evidence to suggest that executive function was both unitary and non-unitary, an integrated model was suggested by Miyake, Friedman, Emerson, Witzki and Howerter (2000). They argued that executive function or specifically the central executive can be fractionated into three separate processes: inhibition, shifting and updating.

Miyake et al. (2000) used confirmatory factor analysis, a structural equation modelling technique, to assess the degree to which the three functions are unitary. They argued that a difficulty of studying individual elements of executive functions is due to the measures not being 'pure', in that a test is not tapping into just one function and could potentially measure multiple functions. They believed that using different measures of the same executive function and extracting what is common across the measures would provide a latent variable which is ‘purer’ and a better representation of executive function. Miyake et al. (2000) chose a number of appropriate tasks to measure inhibition (Stroop task, Stroop, 1935; Antisaccade task, Hallet, 1978; Stop-signal task, Logan, 1994), updating (Keep-Track task, Yntema, 1963; Letter memory task, Morris & Jones, 1990; Tone monitoring task) and shifting (Plus-minus task, Miyake et al., 2000; number-letter task, Rogers & Monsell, 1995; Local-Global Task, Navon 1977).

On a sample of 137 undergraduate students it was determined that diversity existed among the three executive function domains, they were distinguishable from one another. The confirmatory factor analysis revealed that the model of best fit was when the three executive function variables were partially independent but were still correlated. Compared with other models where the three executive function variables were completely independent or one in which all of the measures formed a single central executive function. In summary, the data showed that there was diversity amongst the three executive functions but the inhibiting, shifting and updating functions were not entirely independent from one another. This suggests that the three executive functions tap into some common underlying ability, the functions had both “unity and diversity” (p. 87). Given the complex nature of executive functions, a singular test may not be sufficient to capture the numerous cognitive processes and be reflective of the overarching executive functions. Therefore, a compendium or cognitive test battery would provide an overall view of any impact that executive functions have on a cognitive skillset (Miyake, Emerson & Friedman, 2000).

2.3. Inhibition

Inhibition refers to an individual's ability to inhibit dominant, automatic and prepotent responses. It involves being able to control the thoughts, behaviours and emotions in order for an individual to respond in an appropriate way. Inhibition is not just the self-control of one single aspect of life but of multiple and because of this, similarly to executive function, the definition has been inconsistent and broad and it is often broken down into multiple inhibitory functions (Friedman and Miyake, 2004). Diamond (2013) uncovers these individual facets of inhibition revealing the functions complexities. The inhibitory control or interference control of attention allows us to selectively attend to those stimuli that matter, allowing us to focus on what we choose whilst suppressing other stimuli. For example, this ability allows an individual to go to a busy place such as a party and screen out all but one voice. Interference control also allows the suppression of prepotent mental representations which requires an individual to resist those irrelevant or inappropriate thoughts or memories.

A further aspect of inhibition is self-control, this involves an individual controlling both emotions and behaviours in order to resist temptations and to not act impulsively requiring the discipline to stay on task despite distractions. Inhibition is measured via a number of different performance-based tasks with the most widely-used being the Stroop task (Stroop, 1935). The Stroop task is a validated test consisting of two separate tasks: (1) a colour task to evaluate a participants highly automatic inhibitory skill, where a list of words are presented in numerous different colours and participants are asked to respond with the correct colour that the word is written in, and (2) a colour word task, to identify the colours of the words but with the addition that the words are colours and are printed / highlighted in a different colour. E.g. The visual is of the word ‘red’ which has been delivered in the colour ‘blue.’ Participants must inhibit the natural response to read the word, instead naming the colour of the ink/type. The congruent and incongruent conditions are key to this task with the greater difference in reaction time between the congruent and incongruent accurate trials showing a poorer display of inhibition.

2.4. Updating

Updating is the function of replacing old information in short-term memory with new information (Morris & Jones, 1990). The updating function is heavily associated with working memory, the ability to hold on to and manipulate information and being able to manage any new information which becomes available (Morris & Jones, 1990). As noted earlier in the chapter working memory is thought to manage verbal and visual-spatial information and updating is seen as critical for making sense of what happens in day-to-day life, in that it allows for information to be held in the mind and referred to. Updating also allows us to consider information, to reason and make future decisions based upon remembered stimuli / information. Working memory allows the ability to complete tasks such as reorder a to-do list with the updating functions furthering this and allowing an individual to oversee and incorporate new information into thoughts and current plans. To add to this, updating makes it possible for an individual to adapt to a changing situation and to respond or behave appropriately (Diamond, 2013). Tests such as digit span, letter-number sequence and visual span are used to assess the capacity of working memory and updating. An additional task is the N-back task (Boselie et al.,2016), a task which requires participants to appraise stimuli (i.e., words, shapes) presented on a computer screen and indicate whether each stimulus was the same as the one that was presented a certain number of stimuli ago (e.g. 2-back). Performance is measured by the accuracy of correctly identifying the stimuli. Overall, it requires the retrieval of information from memory and the ability to constantly be updating this information.

2.5. Shifting

Shifting is the ability to change perspectives and approaches to a problem by adjusting to new demands, rules, or priorities. Everyday life requires these frequent shifts to switch between different tasks to adapt to new situations (Monsell, 2003). Shifting is often linked with cognitive flexibility, the latter referring to the ability to the change whilst the former is the process by which these changes can be made but the difference is often blurred and much overlap is seen between the terms (Diamond, 2013). How we respond to different environment objects and events are based upon the task-sets that an individual adopts. In any given circumstance, there are a range of possible actions an individual can take to respond and an appropriate response depends upon the context. We therefore adopt task-sets, to form effective plans to perform a task (Rogers & Monsall, 1995). Some task-sets will be familiar and will utilise memory, such as calling an individual by their given name, other novel task-sets will require the use of instructions or materials. The shifting process is the cognitive capability to be able to move between these task-sets when rules, demands or priorities change. Measures of set shifting are well used within a battery of cognitive tests. Tests such as the Trail Making Test (Reitan, 1992), all include different trials or blocks that assess an individual’s ability to shift between different patterns and rules. This task is split into two parts. Part A requires a participant to connect 25 circles numbered from 1 to 25 with a pen as quickly as possible. Part B requires a participant to connect 24 circles numbered from 1 to 12 with letters from A to L in alternating order as quickly as possible. Time taken to complete each task are recorded with a difference score between the time taken on Part A and Part B. The greater the difference score, the greater the impairment which reflects poor cognitive flexibility. Dual-task tests assign an individual with performing two tasks simultaneously and errors are monitored to assess for the effects and ability of the individual.

2.6. Capacity Theories

An important part of executive functioning is that it allows a person to coordinate their resources through appropriate control and regulation in order to achieve a goal. In every day life, individuals are often involved in actions that combine a number of tasks, known as multitasking. Compared to performance of a single task a combination of a number of activities can be accompanied by performance costs, such a reduced capacity to complete tasks. The performance costs suggest that performing a number of tasks or activities can bring the cognitive processing system to its limits (Strobach et al., 2018). Pashler and Johnston (1989) highlight that when stimuli from two tasks occur in rapid succession a response delay is observed for the second task and research on dual-task performance and task switching performance has typically found this. This should be a consideration when utilising tests of executive function which readily use tasks requiring multiple cognitive operations.

There are two models which account for this delay; the central bottleneck / postponement model and the capacity-sharing / resource model. Proposed by Welford (1952, 1980), the central bottleneck model is supported by a large amount of evidence (Pashler & Johnston, 1989; Ferreira & Pashler, 2002). This theory focuses on the interference which occurs between two tasks which require the exclusive use of a single mechanism, which is dedicated to a cognitive operation for a certain amount of time. When this single mechanism is dedicated to processing a task, it becomes unavailable to process any further information, creating a bottle neck. This means that a second task is postponed until the mechanism becomes available. The alternative theory to this is the resource or capacity theory (Kahneman, 1973; Norman & Bobrow, 1975; Wickens, 1983) which suggests that the capacity to complete both tasks is reduced because they share common resources. In contrast to the previous theory, resource theory does not assume that tasks require the use of a single mechanism, but that general cognitive resources are utilised to support all of the cognitive processes which are required. Performance efficiency is thought to increase as the allocation of capacity to the resources increases (Kahneman, 1973; McLeod, 1977).

2.7. Measurement

The broad number of elements that executive functioning encompasses has led to many different assessment tools being utilised to measure an individual's executive function. The initial understanding of executive function has been derived from neuropsychological testing and standard measures of executive functions have become laboratory based. These standardised tests or cognitive tasks allow an individual to be challenged by situations and tasks which are known to be associated with executive functions. A number of these tasks involve the measurement of an individual's response speed, with some tasks reporting that a significantly slower response time reflects some form of dysfunction. In addition to this, some tasks include further measurements such as the correct response to task questions and for word generation tasks, a time limit is set in which to see how many tasks can be completed within this.

These tasks are often presented alongside each other in a cognitive test battery, a range of tests designed to assess key cognitive processes and abilities. They can include a number of different tasks, each of which are understood to engage one or more executive functions. Examples of tasks include the Wisconsin Card Sorting Task (Milner, 1963). This is a complex performance task where it is suggested that it measures and taps into many different aspects of executive functions, shifting as well as inhibition. A card or computerised version of this task is performed, where a deck of cards is presented depicting different numbers, shapes and colours. The aim of the task is to sort the cards according to one of three rules (i.e., numbers, shapes or colours). Participants are not aware of the initial rule and must figure this out through trial and error, receiving feedback after every sort. Participants must continue to sort in line with this rule but are aware that the rule will subsequently change. When this rule changes participants must shift their attention and sort the cards according to the new rule. The Brixton Spatial Awareness Test (Burgess & Shallice, 1997) similarly requires individuals to deduce what the rule of the task is by trial and error, learning by attending to feedback to complete the task in hand.

Not all measurements are based upon these psychological behavioural / performance-based tests and a number of standardised measures allow an individual to assess and self-rate their own behaviour believing this is a better insight into how everyday life is impacted. This includes Roth, Isquith and Gioia's (2005) Behaviour Rating Inventory of Executive Function (BRIEF-A) which consists of sub-scales which each reflect an aspect of executive function. It is a self-rated questionnaire that assesses for inhibition, shifting, emotional control, working memory, planning/organising, organization of materials, and the ability to monitor. The advantage to using this methodology is that it provides a picture of how an individual perceives that they are being impacted by potential dysfunctions. A performance-based task may be able to identify a dysfunction via a variable such as reaction time, which provides an objective measure, but it does not explain how this affects an individual's life. Self-report measures such as the BRIEF-A should be a consideration when investigating executive function as they are currently underused. The BRIEF-A will be discussed further in Chapter 5.

2.8. Conclusion

The nature of executive function is a complex one and to capture all of the processes which are associated with it, a number of tests are needed to capture this in its entirety. It is clear that a number of different tests of executive function exist and some may target numerous functions. It is necessary to be clear about which areas of executive functions are being tested and a number of tests are needed to capture this. The theoretical model by Miyake et al. (2000) will be used to underpin the executive function work within this thesis.

Chapter 3. A Systematic Review of Obesity and Executive Function

3.1. Introduction

3.1.1. Obesity

The increasing incidence of people affected by overweight or obesity is a significant health problem. The occurrence of obesity contributes to significant health impairments with increases in the risk of diabetes (Hauner et al, 2017), hypertension (Qiu et al., 2005; Jiang et al., 2016) and associations have been made with numerous forms of cancers (WHO, 2011). In recent years it has been suggested that as well as having consequences of a physical nature, obesity is also linked to depression (Luppino et al., 2010) and impairments in cognitive functioning (Elias et al., 2003) with evidence suggesting that increased weight may also result in decreased cognitive abilities independently of associated medical conditions (Smith et al. 2011). Furthermore, there is evidence to suggest that when obesity affects cognitive function this is at the detriment of the capability to make decisions and plan effectively which can lead to the inability to function in everyday life (Gunstad et al. 2007). The specific area of cognition to which these abilities are linked is executive function and in recent years research has begun to focus on the relationship between the executive functions and obesity (Prickett et al., 2015; Favieri et al., 2019; Yang et al., 2018).

3.1.2. Executive function

Executive functions are an 'umbrella term' (Diamond, 2013) for a set of cognitive mechanisms that control and regulate an individual's behaviours and thoughts. Executive functions are compiled of various control functions which include shifting between mental sets, inhibiting dominant responses, updating in working memory, planning and maintaining goals (Miyake & Friedman, 2012). It is believed that executive function relates to high level cognitive processes that allows an individual to manage time, organise thoughts, plan, solve problems and to make decisions (Lezak et al., 2012).

The measurement of executive function has been problematic. A number of different functions have been associated as an execution function and in the past this area of cognition has lacked a theoretical foundation. In recent years, for clarity, much research has centred on three specific processes which were cemented in a pivotal study conducted by Miyake, Friedman, Emerson, Witzki, Howerter and Wager. In 2000, they argued that that the central executive, which is responsible for organising activity within the cognitive system, can be fractionated into three separate processes: inhibition, updating and shifting. Inhibition refers to an individual's ability to inhibit dominant, automatic and prepotent responses (Stroop, 1935), enabling the control over emotional and behavioural responses. Updating refers to the process where individuals monitor and code incoming information and revise information already stored in working memory by replacing irrelevant information with more relevant information (Morris & Jones, 1990). Shifting relates to an individual's ability to switch back and forth between multiple tasks, operations, or mental sets (Monsell, 2003). Further details of this theoretical standpoint can be found in Chapter 2.

3.1.3. Obesity and Executive Function

In very recent years Miyake's theoretical standpoint has been driving the work on obesity and executive function. Work on obesity and executive function remains ambiguous and many obesity theorists have used validated tests to describe executive functions rather than using a clear definition. This has often led to executive functions being measured as a singular function with a limited number of cognitive tests to map out the various aspects of the cognitive functionality.

Despite the relevance of cognitive functions to the overweight and obesity classified groups a lot is still unknown about executive function abilities especially in an adult population, as in recent years much focus has been on childhood and adolescent obesity (Liang et al., 2014). In clinical populations, obese individuals have been found to perform worse on tests of executive functions compared with normal weight individuals (Boeka and Lokken, 2008; Lokken et al, 2010). These findings show that individuals with elevated BMI have reduced executive function performance and are consistent with the growing number of studies linking obesity to poor neurocognitive functions (Yang et al., 2018).

In a recent meta-analysis of the effect of obesity on planning, decision-making, inhibition, cognitive flexibility, working memory, and verbal fluency, Yang et al. (2018) looked to address this gap. They found that obese individuals showed poorer executive functioning across all domains compared to healthy weight individuals with only overweight participants showing significant deficits in inhibition and working memory. Their analysis was inclusive of child and adolescent data which is common practice in reviews of obesity and cognition and it would be of interest to tease out adult data, where in comparison there is little recent work. There is now a suspected association between Alzheimer's disease and obesity, with an elevated weight status becoming a supposed independent risk factor for the onset of dementia (Gunstad et al., 2007). Given this, it would be appropriate to focus on adult populations and to study and analyse if dysfunctions exist or where dysfunctions may evolve, as executive dysfunction may potentially be a moderating variable for Alzheimer's Disease.

However, a further systematic literature review revealed that although impairments in obese adults were found across almost all cognitive domains investigated, numerous methodological limitations were identified which need to be considered in interpretations and conclusions regarding an independent effect. Prickett et al (2015) concluded that whilst cognitive impairments in obese adults were evident, as a result of the methodological limitations, such as a lack of application of exclusions and control variables and use of comparison or normal groups, there is currently insufficient evidence to indicate a reliable and valid independent association between obesity and cognitive impairment in mid-life adults. It was suggested that any further reviews should address these limitations including the use of comparison groups.

The levels of obesity are currently increasing at alarming rates, it is important that the relationship between obesity and executive functions are more clearly understood. Examining the potential factors contributing to the relationship between obesity and these cognitive processes are necessary for prevention of cognitive deficits in the population. A reflection on this relationship may also have implications for understanding other neurological conditions such as dementia.

This systematic review looked to analyse studies that have examined the relationship between executive function and overweight / obese groups in adult populations.

The aims of this systematic review are:

(a) to identify the presence of a relationship between executive functions and overweight and obese groups in adults;

(b) to see if any of the specific executive function domains, led by Miyake's three-factor interpretation of executive function, were associated with overweight and obesity in adults.

3.2. Method

3.2.1. Research Strategies

The systematic review was conducted using PsycINFO, MedLine, CINAHL, EMBASE, Web of Knowledge and Cochrane databases. The following keywords were used: "Executive Function," "Inhibition," "Updating," "Working Memory," "Shifting," Cognitive Flexibility," "BMI," "Overweight," "Obesity." (Figure 2 for Search Strategy). All original, "full-text" papers published in international, peer reviewed journals up to June 10th, 2018 were considered.

Executive function and Obesity: ("executive function" [MeSH Terms] OR ("executive" [All Fields] AND "function" [All Fields]) OR "executive function" [All Fields]) AND (BMI [All Fields] OR ("overweight" [MeSH Terms] OR "overweight" [All Fields]) OR ("obesity" [MeSH Terms] OR "obesity" [All Fields])

Inhibition and Obesity: ("inhibition (psychology)"[MeSH Terms] OR ("inhibition"[All Fields] AND "(psychology)"[All Fields]) OR "inhibition (psychology)"[All Fields] OR "inhibition"[All Fields]) OR "cognitive"[All Fields]) AND ("inhibition (psychology)"[MeSH Terms] OR ("inhibition"[All Fields] AND "inhibition (psychology)"[All Fields] OR "inhibition"[All Fields] AND (BMI[All Fields] OR ("overweight"[MeSH Terms] OR "overweight"[All Fields]) OR ("obesity"[MeSH Terms] OR "obesity"[All Fields])

Working Memory and Obesity: (Updating[All Fields] OR ("memory, short-term"[MeSH Terms] OR ("memory"[All Fields] AND "short-term"[All Fields]) OR "short-term memory"[All Fields] OR ("working"[All Fields] AND "memory"[All Fields]) OR "working memory"[All Fields])) AND (BMI[All Fields] OR ("overweight"[MeSH Terms] OR "overweight"[All Fields]) OR ("obesity"[MeSH Terms] OR "obesity"[All Fields])

Shifting and Obesity: (Shifting [All Fields] OR "cognitive" [All Fields]) AND ("switching" [MeSH Terms] OR "shifting" [All Fields] OR "flexibility" [All Fields]) AND (BMI [All Fields] OR ("overweight" [MeSH Terms] OR "overweight" [All Fields]) OR ("obesity" [MeSH Terms] OR "obesity" [All Fields])

Figure 2 – Search Strategy for Systematic Review

3.2.2. Review Criteria

All the studies which were chosen investigated the relationship between executive functions and overweight and obese weight groups. The studies included at least one overweight or obese group who were classified by the World Health Organisation's BMI classifications and examined at least one executive function. For the selection of the articles the following inclusion criteria were used: (a) academic articles published in "peer-reviewed" journals; (b) studies written in English; (c) studies on humans with overweight or obese BMI classification; (d) studies including participants aged between 18 and 65 years;

(e) studies using cognitive tasks to assess executive function; (f) studies using a normal weight comparative group.

The following exclusion criteria were applied: (a) studies on obesity caused by other medical diseases of metabolic origin; (b) studies considering overweight / obesity in psychiatric conditions (e.g., schizophrenia). This robust methodology allows a clearer examination of the independent effects of elevated BMI on executive function.

The following data was extracted from the selected articles: (a) authors, publication year, country; (b) population; (c) gender; (d) age; (e) BMI; (f) cognitive task and executive function domain; (g) main results observed in the executive function tasks for each of the domains.

3.3. Results

3.3.1. Study Selection

The initial search produced 1,128 articles. 141 duplicate articles were removed for conciseness. 846 articles were rejected according to an examination of both the title and the abstract in line with the inclusion and exclusion criteria. A final total of 141 studies were reviewed. Upon further inspection and in line with inclusion and exclusion criteria 22 articles remained. The flow chart (Figure 3) shows the study selection process, including the number of studies found, records screened and the records excluded.

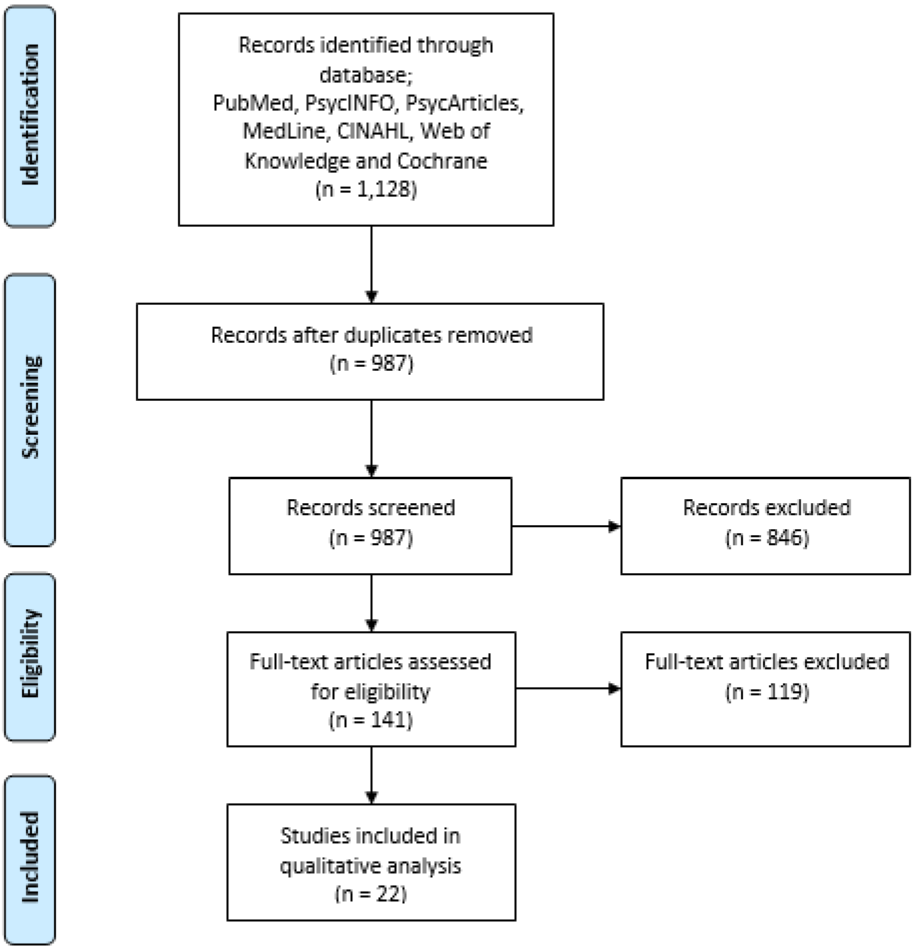

Figure 3 – Flow chart of systematic review process

The systematic search found twenty-two studies that met the inclusion criteria. All the studies used BMI and the related WHO classification to assign participants to different weight groups. All of the studies in line with the first aim of this review examined the differences in performances on tasks of executive functions between participants with obesity and normal-weight. Twenty studies examined the differences between participants who were normal-weight and overweight / obese groups whilst two studies investigated differences in executive function between participants with normal weight, overweight, and obese individuals (Galioto et al., 2013; Navas et al.,2016). Additionally, other groups / categories were examined by research teams including; Anorexia Nervosa (Fagundo et al, 2012;), Binge Eating Disorder (Danner et al.,2011); Low and high high-sensitivity C-reactive protein in obesity (Lasselin et al., 2016) (see Table 3).

All of the twenty-two studies had a higher proportion of female than males, with four of the studies investigating a female only sample (Catoira et al., 2016; Danner et al., 2011; Fagundo et al., 2012; Nederkoorn et al., 2006). Many of the studies used clinical populations with several research groups having access to specific hospital groups (Fagundo et al., 2012), clinic lists (Van der Oord et al., 2018), bariatric programmes (Restivo et al., 2017) and eating disorder groups (Spitoni et al., 2017). Nine studies used participants sampled from a community population (Ariza at al., 2012; Bongers et al., 2015; Catoira et al., 2016; Galiota et al., 2013; Gunstad et al., 2007; Navas et al., 2016; Nederkoorn et al., 2006; Stanek et al., 2013; Stingl et al., 2012); four studies recruited via advertisements and word of mouth (Catoira et al., 2016; Navas et al., 2016; Nederkoorn et al., 2006; Stingl et al., 2012) whilst five studies recruited participants from an existing database compiled as part of wider obesity and health related research (Ariza et al., 2012; Bongers et al, 2015; Galioto et al.,2013; Gunstad et al.,2007; Stanek et al.,2013).

A majority (fourteen) of the studies reported a significant difference across all of the executive functions which were assessed, confirming the relationship between elevated body weight and executive dysfunctions. Only five studies reported no differences (Ariza et al., 2012; Bongers et al., 2015; Nederkoorn et al., 2006; Schiff et al., 2016; Van der Oord et al., 2018) with two studies reporting conflicting differences between and within the executive functions (Catoira et al.,2016; Dassen et al., 2018). Only six studies included the implementation of behavioural testing for all three executive function domains (Ariza et al., 2012; Cohen et al., 2011; Dassen et al., 2018; Restivo et al., 2017; Schiff et al., 2016; Stanek et al. 2013).

Table 3 – Relationship between executive function and overweight / obese groups in adult populations

Author, Year, Country	Population	Group (n)	Sex (% female)	Age M (SD)	BMI M (SD)	Cognitive Task (EF Domain)	Inhibition Findings	Updating Findings	Switching Findings	Decision Making Findings
Ariza et al. (2012) Spain	Community – List acquired from local public medical centres	OB – 42 NW – 42	67 69	31.81 (6.51) 29.67 (6.97)	38.3 (7.59) 22.07 1.97)	SCWT[1] (I[2]) Letter– Number Sequence (U[3]) TMT[4] (S[5]) WCST[6] (S)	No differences between OB and NW	No differences between OB and NW	No differences between OB and NW	
Bongers et al. (2015) Netherlands	Community - larger heritability of obesity study	OB – 185 NW – 134	71 74	35.19 (7.59) 33.04 (8.15)	38.18 (6.17) 22.35 (1.63)	Stop-Signal Task (I) Delay Discounting Task (C)	No differences between OB and NW			No differences between OB and NW
Brogan et al. (2011) Ireland	Clinical - National Weight Management Clinic	OB – 42 NW – 50	71 66	52.24 (10.89) 47.34 (16.34)	41.45 (9.17) 24.36 (3.78)	IGT[7] (C)				OB performed worse than NW
Catoira et al. (2016) Argentina	Community	OW/OB - 81 NW – 32	100 100	30 26.5	35.81 22.56	SCWT (I) WCST (S) TMT (S) Verbal Fluency (S)	OW/OB performed worse than NW		No differences between OW/OB and NW	
Cohen et al. (2011) USA	Clinical – Referrals	OB - 42 NW – 107	48 52	58.9 (8.3) 61.2 (8.0)	31.8 (6.8) 24.1 (1.4)	SCWT (I) Digit Span and Visual Memory Span (U) WCST(S) TMT (S)	OB performed worse than NW	OB performed worse than NW	OB performed worse than NW	
Danner at al. (2011) The Netherlands	Clinical - Psychiatric unit	OB – 18 OB-BED - 19 NW – 30	100 100 100	44.56 (13.36) 38.05 (10.97) 36.13 (14.09)	30.84 (3) 28.74 (6.25) 22.32 (1.96)	IGT (C)				OB performed worse than NW

Dassen et al. (2018) The Netherlands	Clinical - Obesity treatment centres	OB – 82 NW – 71	64.4 77.5	41.12 (12.62) 43.40 (13.44)	38.94 (5.24) 22.63 (1.53)	Stop–Signal Task (I) 2–Back Task (U) TMT (S)	OB performed worse than NW	No differences between OB and NW	No differences between OB and NW	
Deckers et al. (2017) The Netherlands	Clinical - Registration Network Family Practices (Aging project)	OB – 575 NW – 1262	58 46	58 (15) 48.9 (16.2)	31.2 (3.9) 24.9 (2.5)	Concept Shifting Test (S)			OB performed worse than NW	
Fagundo et al. (2012) Spain	Clinical – Hospital Sites (Spanish Research Network)	OB – 52 AN - 35 NW – 137	100 100 100	40.5 (11.1) 28.1 (8.2) 24.8 (7)	39.8 (7.4) 17.2 (1.4) 21.5 (2.7)	SCWT (I) WCST (S) IGT (C)	OB performed worse than NW		OB performed worse than NW	OB performed worse than NW
Galioto et al. (2013) USA	Community - Brain Resource International Database (BRID)	OB – 81 OW - 210 NW – 288	55.9 37.5 58	51.78 (16.96) 50 (17.24) 44.72 (18.37)	34.67 (5.59) 27.12 (1.45) 22.35 (1.73)	Digit Span (U) Switching of Attention Task (S) Maze Test (C)		OB performed worse than NW	OB performed worse than NW	OB performed worse than NW
Gameiro et al. (2017) Portugal	Clinical - undergoing evaluation to have bariatric surgery	OB – 76 NW – 38	68 71	43.24 (9.05) 40.53 (10.75)	>30 <25	Go/No–Go Task (I) SCWT (I) WCST (S) Colour Trait Test (S)	OB performed worse than NW		OB performed worse than NW	
Gunstad et al. (2007)	Community - Brain Resource International Database (BRID)	Younger: OW - 140 NW - 178 Older:	46.4 55.1	32.40 (9.10) 31.56 (8.71)	28.4 (4.42) 22.09 (1.71)	Verbal Interference Task (I) Switching of Attention Task (S) Maze Test (C)	OB performed worse than NW		OB performed worse than NW	OB performed worse than NW

		OW – 58 NW – 32	55.1 53.4	60.4 (7.62) 58.34 (6.62)	29.17 (3.54) 23.09 (1.59)	Verbal Interference Task - Stroop (I) Switching of Attention Task (S) Maze Test (C)	OB performed worse than NW		OB performed worse than NW	OB performed worse than NW
Lasselin et al. (2016) France	Clinical - Services of digestive and bariatric surgery	OB– LowCR - 29 OB– HighCR - 37 NW – 20	62 89 90	39.4 (10.5) 37.9 (9) 38.9 (10.1)	40.7 (3.7) 42 (3.8) 22 (3)	IED[8] (S)			OB–HighCR performed worse than OB–LowCR; NW	
Navas et al. (2016) Spain	Community	OB – 20 OW - 21 NW – 38	55 52 58	32.15 (5.96) 35 (6.31) 33.18 (6.59)	35.5 (2.6) 27.34 (1.59) 22.21 (1.70)	The Wheel of Fortune Task (C) IGT (C)				OB performed worse than NW (WoFT) No differences for (IGT)
Nederkoorn et al. (2006) The Netherlands	Community	OB – 31 NW – 28	100 100	40.9 (6.6) 41.8 (7.4)	39.0 (5.3) 22.5 (2.2)	Stop-Signal Task (I) Delay Discounting Task (C)	No differences between OB and NW			No differences between OB and NW
Perpiñá et al. (2017) Spain	Clinical – Eating disorder patients	OB – 27 NW – 39	85.2 76.9	47.78 (11.46) 31.9 (13.54)	43.92 (10.04) 23.21 (3.48)	WCST (S) IGT (C)			OB performed worse than NW	OB performed worse than NW
Restivo et al. (2017) Canada	Clinical - Bariatric surgery program	OB– Bar - 25 OB– BarDDM - 21 NW – 20	92 90 90	43.9 (10.7) 43.2 (10.9) 43.8 (11)	44.7 (2.9) 43.7 (4.8) 22.4 (2)	SCWT (I) COWAT[9] (U) Color Trail Test (U) PASAT[10] (U) WCST (S)	OB–Bar; OB–BarDDM performed worse than NW	OB–Bar; OB–BarDDM performed worse than NW	OB–Bar; OB–BarDDM performed worse than NW	
Schiff et al. (2016) Italy	Clinical - Nutritional treatment to control	OB – 23 NW – 23	78 78	36.2 (9.5) 33.8 (8.9)	36.2 (5.7) 22.4 (2.2)	Simon Task (I) Sternburg Task (U) TMT (S)	No differences between OB and NW	No differences between OB and NW	No differences between OB and NW	No differences between OB and NW

	Weight					Temporal Discounting Task (C)				
Spitoni et al. (2017) Italy	Clinical - Clinic for treatments of eating disorder	OB – 24 NW – 37	79 65	49.8 (13.66) 35.7 (11.2)	41.1 (8.03) 22.5 (3.01)	BADS-Rule Shift Cards (I) Hayling Sentence Completion Task (I)	OB performed worse than NW			
Stanek et al. (2013) USA	Community - Brain Resource International Database (BRID)	OB - 152 NW – 580	84 55	43.45 (11.28) 47.66 (18)	45.23 (6.91) 25.84 (4.97)	Verbal Interferences (I) Digit Span (U) Switching of Attention Task (S) Maze Test (C)	OB performed worse than NW	OB performed worse than NW	OB performed worse than NW	OB performed worse than NW
Stingl et al. (2012) Germany	Community	OB – 34 NW – 34	70 70	36.5 (9.5) 38.4 (11)	30.4 (3.2) 22 (2.1)	N–Back Visual Task (food cue) (U)		OB performed worse than NW		
Van der Oord et al. (2018) Belgium	Clinical - Pre-bariatric Surgery list	OB – 39 NW – 25	82.1 72	42.82 (13.23) 44.9 (15.32)	39.7 (5.31) 22.94 (1.43)	Stop–Signal Task (I) Chessboard Working Memory Task (U) IGT (C)	No differences between OB and NW	No differences between OB and NW		No differences between OB and NW

[1] Stroop Color and Word Test; [2] Inhibition; [3]Updating; [4]Trail Making Test; [5]Shifting; [6] Wisconsin Card Sorting Test; [7]Iowa Gambling Test; [8] Intra-Extra Dimensional Set Shift; [9]Controlled Oral Word Association Test; [10]Paced Auditory Serial Addition Test

3.4. Literature Analysis

3.4.1. Inhibition

Inhibition refers to the ability of an individual to control automatic and / or dominant responses so that thoughts and actions are appropriate for goal-directed behaviours (Miyake, 2000). Fourteen studies examined the relationship for inhibitory control between the normal weight and overweight / obese groups (see Table 3). Among these studies, nine studies reported differences between the weight groups (Catoira et al., 2016; Cohen et al., 2011; Dassen et al., 2018; Fagundo et al., 2012; Gameiro et al., 2017; Gunstad et al., 2007; Restivo et al., 2017; Spitoni et al., 2017; Stanek et al., 2013).

The literature analysis suggests that the majority of studies support the suggestion that overall, those with an elevated BMI have lower levels of inhibition on behavioural tests of cognitive function. This implies that those who are classified as obese are more likely to struggle to control and inhibit their impulsive actions and thoughts. Literature to support this includes the work by Fagundo and colleagues (2012) who conducted the Stroop Colour and Word Task (SCWT) (detailed in Chapter 2 p. 22) on a sample inclusive of obese participants (mean BMI 39.8 kg/m^2) and normal weight controls (mean BMI 21.5 kg/m^2). It is suggested that those with poor inhibition skill will take longer to respond to the differences in colours and words and if measured, would make more errors than those with functional inhibition skills. Fagundo et al. (2012) reported that the obese sample performed worse on the Stroop task compared with the normal-weight controls, specifically in relation to the Stroop interference score. This suggests that those classified as obese may have difficulty controlling inappropriate automatic and dominant thoughts and actions with the research group concluding that the detriment of extreme weight conditions extends to executive dysfunctions.

Likewise, Gameiro et al. (2017), also utilised the SCWT to study executive functions in obese patients waiting for clinical treatment. In total 114 adults, 76 obese (BMI > 30 kg/m^2) and 38 normal weight (BMI < 25 kg/m^2) completed the inhibition task and it was found that the obese group had slowed colour-naming, taking more time to respond to the colour word task than the normal weight participants (p=.020). They suggest that these results can indicate that those in the obese category are more likely to have difficulties responding to cognitive interference and this therefore hinders their inhibition capacity.

Spitoni (2017) focussed solely on tests of inhibition and supports the findings that inhibition ability is at a disadvantage when BMI is raised. The sample of 24 obese patients (mean BMI 41.1 kg/m^2), admitted to a specialised clinic and 27 healthy weight controls (mean BMI 22.5 kg/m^2) completed two tests of inhibition; the Rule Shift Cards (RSC) (Wilson et al., 1996) and Hayling Sentence Completion Task (HSCT) (Burgess and Shallice, 1997). The RSC testing for inhibition via a rule change card task whilst the HSCT requires participants to complete sentences using reasonable and unreasonable words. On both the RSC and the HSCT the time taken and the number of errors were recorded, with poor performance of inhibition related to slower reaction times and more errors made. Spitoni et al. (2017) recorded general linear model results for both tests of inhibition, RSC and HSCT, revealing that obese patients had poor scores on tests of cognitive inhibitory control showing significantly impaired performance both in the time needed to complete the inhibition tasks and in the number of errors compared to healthy weight controls. The slower reaction times were not counterbalanced by greater accuracy, the obese sample made more errors than the healthy weight controls. This supports that the obese population are likely to experience more difficulties in managing the inhibition of a pre-learned behavioural rule.

In contrast to this, literature within this review suggests that the difference between the weight groups and inhibition does not provide significant results (Bongers et al., 2012; Van der Oord at al., 2014). Ariza et al. (2012) focused their research on the interaction between dopamine genes, executive function and an obese population. In a community sample, 42 obese participants (mean BMI 38.3 kg/m^2) were matched by age, education, gender and measures of overall anxiety and depression with 42 healthy weight (mean BMI 22.07 kg/m^2) participants. They completed a number of neurological assessments including the WCWT and results found no relationship between obesity and worse performance on executive function variables including inhibition ($p=0.403$), there being no significant effect of 'group' on any of the executive function variables.

There are several cognitive tasks which test for the same executive function and any potential differences in outcomes may be due to study groups utilising different behavioural tests. Interestingly, within this review differences are reported even when the same cognitive test for inhibition is used. This is most apparent in relation to the stop-start task (Logan et al., 1997). The stop-start task is a measure of impulsivity, based on the premise that impulsivity is related to the inability to inhibit automatic or dominant responses. In this test participants perform a reaction time task 'start-task' in which they are required to respond to a stimulus as quickly as possible. On a subset of trials, an additional stimulus ('stop-task') instructs participant to abort the response which they have already initiated. A slower reaction time in stopping or aborting this task shows less inhibitory control.

Dassen et al. (2018) implemented the stop-start task as a test of inhibition on a sample of obese clients from an obesity treatment centre. The 82 obese patients (mean BMI 38.94 kg/m^2) and 71 healthy weight controls (mean BMI 22.63 kg/m^2) were matched on age, gender and education level. They found that performance on the general stop-start task differed between the obese group and healthy weight controls, those with obesity displaying significantly less efficient inhibition ($p<.001$). A food-specific Stop-Signal Task was also utilised and the same results were observed.

In contrast, Nederkoorn et al. (2006), using a female only community sample of 31 obese participants (mean BMI 39.0 kg/m^2) and 28 normal weight (mean BMI 22.5 kg/m^2) participants found that the stop-start task did not provide clear evidence of an inhibitory deficit in obese participants. The group found that there was not a significant difference for reaction time between the weight groups ($p=0.18$). Additionally, this research group found a significant difference for a group block interaction. Within this task, whilst only marginal differences were seen throughout the first blocks of the trial, during the last block obese participants began to differentiate from the healthy weight group and a significant difference was noted. It seems that at this later point the obese groups begin to have difficulties with inhibiting responses compared to the healthy weight controls. They conclude overall that there are no clear differences between the groups but results suggest obese individuals had problems in maintaining performance across the duration of the task.

3.4.2. Updating

Updating refers to the aspect of executive functions which requires the monitoring of incoming information which is relevant to a task, thought or action and then appropriately reviewing the items held in working memory by replacing old, no longer relevant information with newer, more relevant information. This concept is heavily linked to working memory (Morris & Jones, 1990; Miyake 2000). In comparison to the other executive functions appraised in this review, cognitive tests of updating were often overlooked in favour of other executive functions. Of the nine studies that analysed the relationships between the weight groups and updating tasks (see Table 3), inclusive of tests of working memory, five observed differences between the groups (Cohen et al., 2011; Galioto et al., 2013; Restivo et al., 2017; Stanek et al., 2013; Stingl et al., 2012).

The majority of findings suggest that those with an elevated BMI were reported to have lower levels of updating ability on behavioural cognitive tests, suggesting that those with raised weight levels are not able to Keep-Track of information compared to healthy weight individuals. Stingl et al. (2012) was the only study reviewed which focused exclusively on the updating domain of executive function. A sample of 34 obese (mean BMI 30.4 kg/m^2) participants and 34 lean (mean BMI 22.0 kg/m^2) participants completed the N-Back Visual Task (Boselie et al.,2016) (detailed in Chapter 2 p. 23). Stingl et al. (2012) found a main effect for accuracy ($p=0.014$) showing that the lean weight group correctly responded to the stimuli significantly more than the obese group, concluding that increased body weight is associated with reduced task performance.

This is further supported by Cohen et al. (2011) using a sample of 41 overweight and obese participants (mean BMI 31.8 kg/m^2) matched by age, gender and race to 98 lean (mean BMI 24.1 kg/m^2) weight participants. Using the Digit Symbol Substitution Test (DSST) from the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 2008), participants are presented with a single sheet of paper on which they are required to match symbols to numbers according to a key located on the top of the page. The lean group outperformed the overweight and obese group, correctly remembering more of the symbols ($p=0.03$). The outcomes suggested that the overweight and obese weight group were likely disadvantaged and had difficulties remembering the task rules which are required for the continual updating of required symbol-digit pairs.

In contrast, in 2016, Schiff and colleagues consented normal weight (mean BMI 22.4 kg/m^2) participants matched by education and age to obese patients (mean BMI 36.2 kg/m^2). To test for working memory capacity the Sternberg task (Montagnese et al., 2012;

Sternberg, 1966) was employed where participants are required to indicate whether a single number presented was present in a previous number set. The task assesses how well individuals store and retrieve information from short-term memory with the number of correct responses providing an accuracy score. They found that the weight groups did not differ on this task of working memory. This is supported by Ariza et al. (2012) and Van Der Oord et al. (2018) who both concluded that individuals with obesity showed no differences on tests of updating between the weight groups.

Furthermore, Dassen et al (2018) did not find any differences between obese and healthy weight individuals on the 2-Back Visual Task, a version of the N-Back Visual Task ($p=0.81$). However, the opposite was found when testing for working memory using a self-reporting methodology; The Behavioural Rating Inventory of Executive Functioning-Adult Version (BRIEF-A) (Roth & Gioia, 2005). The BRIEF-A is a 75-item standardised rating scale developed to provide an understanding of the everyday behaviours associated with specific domains of executive functioning in adults. The participants had to indicate for each item whether the statement applied to them on a 3-point Likert scale. Using this self-report method, a significant difference was found between the obese and normal weight groups. This suggests that although no significance was found for behavioural tasks, self-reported every day behaviours known to be controlled by working memory processes are perceived to be weaker in the obese weight group. This was the only study within this review which utilised both self-report and behavioural methodologies to test for updating. It is interesting that this research team concluded that using the N-Back Visual test which is purportedly meant to tap into the updating executive function was not reflected in the results of the updating self-reporting methodology. In this case, two methodologies which were predicted to be aligned showed differences. It may be the case that the self-report and performance-based measures assess updating differently or tap on to different levels of the function. This review is limited in that few studies have utilised both methodologies and this should be a future consideration.

3.4.3. Shifting

Shifting refers to the ability to shift back and forth between a number of different tasks (Miyake, 2000; Monsell, 1996). Fourteen studies assessed the differences between the weight groups on cognitive tasks of shifting (see Table 3). Ten of the studies found differences in shifting between normal weight and overweight/obese groups (Cohen et al., 2011; Deckers et al., 2017; Fagundo et al., 2012; Galioto et al., 2013; Gameiro et al., 2017; Gunstad et al., 2007; Lasselin et al., 2016; Perpiñá et al., 2017; Restivo et al., 2017; Stanek et al., 2013). The literature analysis revealed that those with an elevated BMI are reported to have more difficulties on behavioural cognitive tests of shifting, suggesting that excessive weight is in some way linked to an individual's ability to switch between thoughts, actions and emotions.

In 2017, Deckers and colleagues published a large-scale prospective cohort study, using a sub-sample of 545 obese (mean BMI 31.2 kg/m^2) and 1262 normal weight (mean BMI 24.9 kg/m^2) individuals. The team were able to look at executive function (specifically shifting) across three time points; baseline, 6 years and 12 years. The information for each was collated from a database where participants underwent a comprehensive assessment of lifestyle, medical and neurocognitive measures, including the Concept Shifting Task (Van der Elst et al, 2016). This is a three-part task in which a participant is required to cross out as quickly as possible sixteen digits in ascending order, letters in alphabetic order, and finally eight digits and eight letters in alternating order. The research team found that at the baseline time point obesity was significantly associated with a decline in the shifting function ($p=0.03$) independent of other factors including cardiovascular risk. Interestingly, participants with incident obesity who developed obesity over the course of the 12 year study performed worse on this task at baseline but showed less decline during the study period compared with the healthy weight group. This research group concluded that they found a confirmed association between obesity and cognition but results were confounded by age which may account for the interesting decline from the healthy weight group over the 12 years.

Lasselin et al. (2016), further supports the conclusions that shifting abilities are associated with excessive weight. In a study that primarily explored the shifting arm of executive function 66 severely or morbidly obese patients were recruited from a digestive and bariatric surgery service alongside a group of 20 non-obese participants (mean BMI 22.0 kg/m^2). This study was specifically interested in inflammation and high-sensitivity C-reactive protein (hsCRP) and further split the obese group into separate lower (mean BMI 40.7 kg/m^2) and higher (mean BMI 42.0 kg/m^2) hsCRP groups. The groups completed the cognitive intra/extra-dimensional set shift (IED) test, extracted from the CANTAB (Sahakian and Owen, 1992), a task using colour filled shapes and white lines where a rule is learnt by correctly touching stimuli over a series of trials, new stimuli are presented, rules are changed and to complete the task attention has to be shifted appropriately. An increased number of errors and increased number of trials to complete the test would be considered a dysfunction in shifting. This reduced performance was seen in the obese participants with high level hsCRP in comparison to the low level hsCRP and normal weight groups. For the focus of this review, both the lower and higher level hsCRp obese groups performed worse than non-obese participants. This indicates that alterations in attentional set shifting in obese patients are apparent but the research group goes onto conclude that these results may not be entirely due to obesity or to weight gain but may rely on inflammatory processes, which have been associated with reduced cognitive function, specifically impaired shifting ability.

Contrary to the findings that shifting is associated with weight, Catoira et al. (2016) found that the difference did not exist within their normal weight and obese sample. In a study inclusive of 83 obese patients (mean BMI 35.81 kg/m^2) and 32 healthy weight controls (mean BMI 22.56 kg/m^2) they employed the Wisconsin Card Sorting Test (WCST) (Milner, 1963) (detailed in Chapter 2 p. 26). In this sample, when evaluating for the correct responses, the number of errors and the categories completed there were no differences between the groups. The WCST is a widely-used test of executive function and within this review, when using this task, many studies have found clear differences between the normal weight and obese categories (Cohen et al, 2011; Gameiro et al., 2017; Perpiñá et al., 2017; Restivo et al., 2017). Confirming this position, Fagundo et al. (2012) found that their obese group performed significantly less well than healthy weight controls, showing less flexibility of thought compared with the healthy weight control group. They concluded that the obese group were capable of acquiring the first rule but were unable to change their behaviour after this. In other words, they have difficulties switching from a learned behaviour to a new behaviour.

Employing the Trail Making Test (Reitan, 1992) (detailed in Chapter 2 p. 24) there is a similar pattern of inconsistent results. Cohen et al. (2011) found that lean participants took significantly less time than the overweight and obese participants to complete the Trail Making Test (p=0.04). Contradictory findings from other research teams did not find these differences between obese and healthy / lean weight groups on this test of executive function (Ariza et al., 2012; Catoira et al., 2016).

Dassen et al., (2018) additionally did not find a difference in shifting between the weight groups (p=0.30). This is the only study reviewed which when testing for more than one of the domains of the executive functions showed a difference between the functions; with significant differences between the groups for both updating and inhibition but not for shifting. They conclude that the use of behavioural cognitive tasks to test for executive functions may not always be suitable with many of the tasks initially used to indicate brain damage in patients (Luria, 1966). To be used in the capacity that they are employed during tests between obese and normal weight groups, they may not be sensitive enough to pick up the subtle impairments in shifting ability.

3.4.4. Decision-Making

A number of the studies included within the analysis picked up on the executive functions not clearly associated with inhibition, shifting and updating. These included tests of decision-making which are regularly used in studies where eating behaviours and decisions are the main contributors to the research. They have been included here as complex tasks which map on to problem solving and decision making.

Twelve studies (see Table 3) investigated differences in performance between groups on tasks including problem solving and decision making. Of these studies, eight studies found differences between the weight groups (Brogan et al., 2011; Danner et al., 2011; Fagundo et al., 2012; Galioto et al., 2013; Gunstad et al., 2007; Navas et al., 2016; Perpiñá et al., 2017; Stanek et al., 2013). Within this literature analysis, a number of studies confirm that individuals with obesity performed worse on these decision-making tasks compared with a normal weight group.

Confirming this relationship is Brogan et al. (2010) when comparing a sample of 42 obese participants (mean BMI 41.45 kg/m^2) from a National Weight Management Clinic at a general hospital to 50 normal weight (mean BMI 24.36 kg/m^2) participants matched for age, gender, and education. Utilising the Iowa Gambling Task (IGT) (Bechara et al, 2005) participants are required to take part in a simple card task with the goal of earning money where they can win or lose virtual money by choosing cards from four different decks. An impairment in decision making is observed if more disadvantageous than advantageous choices are made. Brogan et al. (2010) found that the obese sample were significantly impaired on the IGT compared to the matched healthy weight group ($p=0.02$) and showed a failure to learn across the task. The matched group showed an increasing preference for advantageous decks across the task whereas the obese participants failed to learn as the task progressed. Furthermore, the obese group did not demonstrate a clear strategy, with no change in preference towards either the advantageous or disadvantageous decks.

Corroborating these findings, in 2012, Danner and colleagues, with a female only sample, agreed that the obese group performed poorly on the IGT compared with normal individuals. Again confirming that the obese group did not improve their choice behaviour over time, whereas participants who were a normal weight showed a learning effect and were therefore able to make better decisions. However, more recently, in 2017, Navas et al. contradicted this finding, demonstrating no differences between normal weight, overweight and obese individuals in the number of disadvantageous choices made. They concluded that this was due to adequately controlling for potential confounds including age, gender and education level but these same confounds were also controlled for in the Brogan et al. (2010) study with a difference in outcomes. Observed discrepancies could be due to the population, Navas et al. (2017) used a community-based population whilst Brogan et al. (2010) used a clinical population. This access to a clinical group provided double the number of obese participants and also a higher mean BMI by 5.95kg, a considerable difference which may account for why this study observed significant differences between the groups.

Another test of decision making frequently used is the Delay Discounting Task (Richards et al., 1999), a similar task to the IGT in that participants are presented with choices between hypothetical monetary rewards, of which one is a smaller immediate reward, and the other is a delayed larger reward. The expectation is that those who are poor at making decisions will choose more often the immediate reward. Bongers et al. (2015), implementing this task on their community population of 185 obese (mean BMI 38.18 kg/m^2) and 134 healthy weight (mean BMI 22.35 kg/m^2) participants, found that there was not a significant effect of weight status on delay discounting scores ($p=.134$). Likewise, Nederkoorn et al. (2006) observed no differences between the obese and normal weight groups ($p=0.30$). It is worth noting here that Schiff et al. (2016), using a similar Temporal Discounting Task (Ainslie, 1974) similarly found that there were no clear differences between the weight groups. However, the obese group did respond more impulsively and chose immediate rewards when the stimulus was a food orientated reward e.g. chocolate bars, cookies. When the reward stimulus was voucher / monetary based they found no differences in decision-making between the obese and normal weight groups, suggesting that these tests inclusive of food related rewards or stimuli may be linked to the desire to have an edible outcome and not just to decision-making. This also show that general impulsiveness may not just be limited to food-related rewards but when food is involved, they choose immediate over delayed gratification.

3.5. Discussion

In this systematic review of executive functions and obesity, cognitive task evaluations frequently found there to be dysfunctions in obese individuals compared to normal weight individuals in adult populations. Overall, the association between obesity and difficulties on tests of executive function is suggested for all three domains of executive functions; inhibition, updating, shifting. However, there are a number of inconsistent results.

Within the small number of studies which implemented the testing for all three executive function domains (Ariza et al., 2012; Cohen et al., 2011; Dassen et al., 2018; Restivo et al., 2017; Schiff et al., 2016; Stanek et al. 2013) the differences between and within the studies do not confirm with certainty that impairment of executive function is linked with excessive weight, just that certain functions (i.e. updating, shifting, inhibition) are linked to a dysfunction within that population. It therefore seems dismissive to provide an overall conclusion that executive function is hindered by excessive weight when only a small number of samples have completed tests to account for the complete picture of executive function theorised by Miyake et al. (2000).

Shifting, updating and inhibition abilities are not entirely independent from one another (Miyake et al., 2000). Many of the studies within the review utilised complex cognitive tests such as the WCST. This test is associated with the ability to switch and shift information but this is a complex task and it is important to consider that a test such as this may load on to additional cognitive functions beyond just shifting (Fagundo et al., 2012; Nyhus et al., 2009). Enhanced or reduced performance in this task cannot be concluded to be because of a singular function, complex tasks have the potential to tap into alternative executive functions and this must be considered when analysing. Miyake et al. (2000) chose tasks to target specific executive functions i.e. to measure the shift, inhibition or updating ability on an individual level, the functions were clearly distinguishable and despite this the unity of the functions was still confirmed. Miyake suggests that it is important to systematically administer multiple executive tasks to understand the nature of impairments in patient’s executive functioning and the use of multiple tests of executive functioning should be examined in relation to weight groups in future studies.

Although the analysis of the studies confirmed that there is an association between executive function and obesity, there were a number of studies which failed to confirm this relationship. Some of those studies such as Schiff et al. (2012) had a very small sample size and although the results are relevant, they must be interpreted cautiously as they may not provide a generalisable overview of weight related behaviour. Of real interest are the smaller proportion of studies using weight groups from a community population which can provide an insight into the functions in a general population. These studies determined that there were no differences between the weight groups on all or on singular task of executive function. (Ariza et al., 2012; Bongers et al., 2015; Catoira et al., 2016; Navas et al., 2016; Nederkoorn et al., 2006). These samples were driven purely via advertisements and other existing lists to recruit both the obese and the normal weight groups. Comparatively with the clinical studies they used larger sample sizes. In the clinical populations, where recruitment was by existing clinical case groups, the majority of the studies found a clear association that excessive weight negatively impacted upon executive functions. Some work from clinical obesity groups performed equally well as the normal weight groups potentially posing questions as to the origin of samples in the vast majority of executive function and obesity research. Within the clinical groups the obese groups BMI are generally higher and they have potentially been referred due to experiencing other health concerns which may not have been captured by the exclusion criteria. As previously noted, few studies have included the application of cognitive tasks for all executive functions including inhibition, updating and shifting with even less research coming from a community sample. An overview of executive functions from a community-based sample would be useful to further address the impact of executive dysfunctions on this population, so that we have knowledge on executive function in a broader range of obese people not just those with clinical referrals.

Many of the studies attempted to control for certain variables including, age, gender and education that might influence executive function performance by matching samples whilst some also controlled statistically for them (Deckers et al., 2017; Perpiñá et al., 2017). Gunstad et al. (2007) found a relationship between BMI and the cognitive tests, but the reduced executive function performance only varied between normal weight and obese adults when adjusting for possible confounds. This highlighted the importance in controlling for such variables to strengthen results.

Age was a common discussion point, many studies in this review were very interested in aging due to evidence that obesity was becoming commonly linked to adverse neurocognitive outcomes including Alzheimer’s disease. Gunstad et al. (2007) attempted to determine whether the relationship between body mass index (BMI) and cognitive performance varies as a function of age and it emerged that there was no interaction. Conflictingly, Stanek et al (2013) concluded that for tests of executive function, BMI was not the independent predictor of poor cognitive performance. The addition of age to the model was a better fit and it suggested that there was an association between higher age and BMI and poorer executive functioning. Gender balancing within the weight groups was noted by Gameiro et al. (2017) as an area of importance for research moving forward. They discovered within an obese group that significant gender differences were observed on a shifting variable, with female responses suggesting higher levels of cognitive inflexibility. The female sample represented a majority of those in the obese group and a balance of genders would have provided stronger outcomes. The consideration of these individual variables should be made.

The role of depression related to BMI appeared to alter the relationship between obesity and executive functions (Restivo et al., 2017). The positive association between depression and obesity in the general population is well known (Luppino et al., 2010) as are the associations between depression and cognition (Elias et al., 2003). Restivo et al., (2017) confirmed that when levels of depression in obesity are high, individuals appeared to perform worse on tests of executive function specifically those for shifting and decision-making. Interestingly a number of studies reported demography for measures of depression but only a small number of studies controlled for depression statistically and although there is widespread association between weight and depression, this warrants further examination in relation to executive functions in an obese population.

A small number of research groups included self-reporting methodologies as well as behavioural tests. This inclusion is logical, executive functions are very much related to the ability to successfully function in daily life and this methodology gives insight into if and how a potential dysfunction affects this. The majority of the studies employing this method used self-report methodologies to analyse impulsivity in regards to decision making (Bongers et al., 2015; Fagundo et al., 2012; Nederkoorn et al., 2006; Schiff et al., 2016). Whilst some found similar results across both self-report and behavioural methods (Fagundo et al., 2012), others described differences between the self-reported impulsivity traits and the behavioural testing of impulsivity traits (Bongers et al., 2015).

Dassen et al. (2018) was the only study to report and compare self-reporting methodology with behavioural methods for the executive functions; inhibition, updating and shifting, using the Behavioural Rating Inventory of Executive Functioning-Adult Version (BRIEF-A) (Roth & Gioia, 2005). The behavioural measures for each of the functions were found to be associated with the self-report measures, more so the positive association between the inhibition methods. Dassen and colleagues note that self-report measures of executive function were included to capture different aspects of executive function; behavioural cognitive tasks to measure the efficiency of cognitive abilities while the self-report measures to assess goal accomplishments in daily life (Toplak et al., 2013). Still, if a behavioural measure highlights a dysfunction then this would have the potential to impact everyday behaviours and therefore it may be that goal achievement or a lack of it could be reported using self-reporting methodology. Mild dysfunctions on cognitive tests may translate into more substantial difficulties in daily living and self-reporting may be the window to understand this (Stanek et al., 2013; Lezak, 1995).

Concerning the BMI groups, all of the studies reviewed explored the differences between a normal and obese weight group with few studies including the addition of an overweight group. No differentiations were made between the extreme obesity BMI classifications (WHO, 2003). This has led to the comparison of research based upon a single variable, 'overweight/obese' or 'obese', where the severity of obesity can range from 25kg/m^2 to upwards of over 40kg/m^2. Navas et al. (2016) revealed that obese individuals made riskier decisions in a decision-making task compared to overweight individuals, which highlights that we should not assume overweight and obese individuals will perform at the same level. There is the potential to be more sensitive and to delve into the differences between these overweight and obese groups.

Additionally, the importance of examining weight across the entire BMI scale is further supported from the small amount of underweight work. Although not the focus of this review, Fagundo et al. (2012) recruited underweight patients as an addition to the obese and normal weight groups and they established an interesting pattern for shifting and decision making. Both the underweight and obese groups performed similarly on the behavioural tasks, concluding that within this clinical sample those at either end of the BMI spectrum exhibited a similar executive dysfunction profile. It is important to explore the similarities and differences between these groups and provide a better understanding of how these groups function cognitively. This may lead to programmes to help improve on executive dysfunctions which can be shared by those at both ends of the spectrums. It would therefore be interesting for further research to see if the trend observed by Fagundo et al. (2012) is mirrored in a non-clinical setting.

This systematic review was not able to identify if one specific executive function had a more significant role than another or provide a clear relationship between obesity and executive functions. This could be because tests of executive function are limited and may be due to the heterogeneity of cognitive tasks (Yang et al., 2018). When reviewing studies, Yang et al. (2018), were hesitant to draw conclusions between them because the analysis of task versions, single tasks and the dependent variables could vary across each study. Further to this, some neuropsychological tests are designed to be used on brain-injured populations and may be less sensitive to subtle impairments in other individuals compared to tests which were designed to highlight individual differences in a 'normal' group. This could account for the inconsistencies, as the way in which cognitive tasks can be utilised may be different for each study with different versions and length times.

The research in this review shows inconsistencies between the normal and obese populations which we often associate with the test themselves or obesity-related comorbidities. Some researchers propose that these differences may be due to mechanisms that could contribute to the independent effect of obesity on cognitive function. This includes structural brain changes between normal and obese individuals. It has been demonstrated that obese individuals have greater brain atrophy, a loss of cells or neurons and the connections between them (Ward et al., 2005; Gunstad et al., 2008). Others have found that obesity is related to lower volumes and cortical thickness in the frontal cortex (Pannacciulli et al., 2006; Taki et al., 2008; Walther et al., 2010; Wang et al., 2017). Obesity is often associated with a chronic low-grade inflammatory state which can lead to an increase in inflammatory markers, such as c-reactive protein (Lasselin et al, 2016). It has been evidenced that inflammation within the central nervous system can induce behavioural changes, of which cognitive alterations is one with memory and attentional disturbances identified (Raison et al., 2006; Dantzer et al., 2008; Capuron and Miller, 2011). Furthermore, c-reactive protein has been associated with lower cognitive scores among obese females on tasks of decision-making and working memory (Sweat et al., 2008).

3.6. Conclusion

To conclude, the analysis of studies supports the existence of executive deficits in obese participants, with evidence across all three domains of inhibition, updating and switching. Although it remains unclear what the true relationship is as there are only a small number of studies implementing behavioural tasks to tests for all three facets of executive function (Miyake et al. 2000). More evidence is needed to assess the significance of individual executive functions across the range of BMI classifications specifically within a community population, as well as the importance of controlling for age, gender, depression and including underweight in a community setting. An indication of the real word implications of reduced cognitive ability on weight groups would also help in developing cognitive strategies for obese and /or individuals with dysfunctions, as well as to more fully appreciate the impact of dysfunctions on daily life.

Chapter 4. Study One

4.1. Brief Introduction

Currently in England, more than 6 in 10 adults are overweight or obese and obesity poses a major risk for type 2 diabetes, cancer and cardiovascular disease (Health Survey for England, 2019). In addition to the physical consequences is the suspected association between Alzheimer's disease and obesity, it has become a supposed independent risk factor for the onset of dementia (Gunstad et al, 2007). Tests of executive functions have provided useful information regarding cognitive dysfunctions in those with an obese BMI (Gunstad et al, 2007; Gunstad et al, 2008; Fergenbaum et al, 2009).

Executive functions are high level cognitive mechanisms that manage everyday thinking and behaviour. The area is ambiguous and many, including obesity theorists have used validated tests to describe executive functions rather than using a clear definition. A recognised model developed by Miyake, Friedman, Emerson, Witzki and Howerter (2000) propose a three-factor interpretation of executive function: 1. information updating (updating and monitoring of working memory representation), 2. shifting (shifting back and forth between multiple tasks or mental sets) and 3. inhibition (the ability to deliberately inhibit dominant or automatic responses when necessary).

In a clinical setting, obese individuals have been found to perform worse on tests of executive functions compared with normal weight individuals (Cohen et al., 2011; Restivo et al., 2017). These findings which show that individuals with elevated BMI have reduced executive function performance are consistent with the growing number of studies linking obesity to poor cognitive performance. It should be noted that overweight and obese individuals frequently have medical conditions with known cognitive consequences and may show poorer test performance (Gunstad, 2007). In contrast to this there are research groups which are challenging this idea and balancing out this argument, where a difference in executive function performance between the weight groups is not found (Nederkoorn et al., 2016; Ariza et al., 2012).

The literature linking obesity and cognitive performance is problematic for several reasons. The first is the sparse amount of studies implementing all three executive function domains, with the majority of adult data researching a single or a maximum of two executive functions. In line with Miyake theory that a large set of cognitive abilities are involved in executive function, it would be useful to provide an overview of these abilities rather than just targeting a single function. With executive functions managing everyday thinking and behaviour and its potential to impact our daily activities it is imperative that we examine it more thoroughly.

In the systematic review (Chapter 3), participants have predominantly been recruited from clinical samples and databases with the focus on the morbidly obese. The problem with much of the current research is that the original focus was not just on the relationship between cognition and obesity – original aims were based upon the influences of metabolic syndrome or weight loss. This has meant that much of the research has primarily come from clinical populations with the comparison of participants classified as 'obese' and 'morbidly obese', with limited comparisons within these studies that can assess dysfunctions across the entire BMI classification range and small proportion of studies using weight groups across a community population. It is important to examine lower BMIs and studies with community samples to provide a better understanding of weight and cognitive associations which in turn could provide better outcomes for those who are at risk of cognitive dysfunctions.

Lastly, not all studies have controlled for depression; a factor known to affect cognitive abilities and obesity (Elias et al., 2003). Both depression and obesity are widely spread problems with major public health implications (WHO, 2020). Due to the high prevalence of both depression and obesity, and the fact that they both carry an increased risk for cardiovascular disease, a potential association between depression and obesity has been presumed and repeatedly been examined. Such an association has been confirmed and a reciprocal link between depression and obesity has been reported. Obesity has been found to increase the risk of depression and in some cases depression was found to be predictive of developing obesity (Luppino, 2010; Faith et al., 2011).

As noted in the systematic review (Chapter 3 p. 35) four out of twenty-two studies were female only. Gender differences were observed on tasks of shifting with females performing better than men (Gameira et al, 2017). A large number of the studies analysed in the review had a larger female sample and gender-balancing should be a consideration for future research. Grissom and Reyes (2019) provide a review of studies of executive function and found that although significant differences were often not found, there were differences between some aspects of the function. In an attention focussed studies it was concluded that females had slower reaction times than males (Giambra and Quilter, 1989; Plitzer et al., 2017). Tasks that involved decision making such as the Iowa Gambling Task again resulted in limited gender differences but it seems that there was some dependence on a part of the task design, specifically that which controls the frequency of gains and losses, with females more likely to avoid the frequency of large losses compared to men (van den Bos et al., 2013; Dretsch & Tipples, 2011). An additional meta-analysis with an interest in working memory tasks found that genders have particular advantages, females have the stronger ability for location memory whilst the males have a better ability to complete n-back tasks (Voyer et al., 2017).

It is therefore vital to continue to examine for male and female differences on tests of executive function. Differences in executive function in previous research has not been able to conclude that gender is the primary factor in differences in executive function ability but clear differences have been found. It is important to provide a better understanding of gender differences across the individual executive functions in a community setting.

The systematic review also highlighted the importance of examining weight across the entire BMI scale from an underweight group to the obese groups. Only one study in the review involved the collection of underweight data. Fagundo et al. (2012) established a pattern of deficits for the shifting and decision-making behavioural tasks for both the underweight and obese groups. The cognitive mechanisms in these groups show signs of similarities which should be explored in more depth to provide a more substantial insight into this area.

4.2. Aims

Study One looks to address some of these limitations by evaluating executive functions across a range of weights (BMIs) in a community population. The study looks to evaluate the relationship between weight and executive function.

The aims of this study are:

(a) to identify any association between weight and executive function when controlling for depression, age (and other potential clinical confounders) in a community sample.

(b) to determine at what level of BMI are cognitive deficits evident and which, if any, cognitive deficits are evident.

(c) to see if any associations are consistent across the executive functions: shifting, updating and inhibition.

4.3. Methodology

4.3.1. Ethics

All participants provided written informed consent prior to participation. Informed consent was obtained by the principal researcher. All participants were made aware that participation was entirely voluntary and that they were free to withdraw at any time and no reasons would have to be given.

The University of Central Lancashire PsySoc Committee granted full ethical approval for this project (ref. PSYSOC 199) and is included in Appendix 1. All personal data used within the study was maintained in accordance with the Data Protection Act 1998. Upon recruitment into the study, all participants were given a unique identification (ID) number which was used on all future paper and computer records. There was one document linking the names to the ID numbers which was kept in a locked cabinet in a secure office in the Darwin Building on the University of Central Lancashire (UCLan) campus.

All computer records were password protected and made anonymous, whilst paper records were stored in a separate locked filing cabinet on UCLan campus. Upon study completion, all personal data including paper demographic records and paper cognitive test answers were kept in a locked filing cabinet on UCLan campus for 5 years.

4.3.2. Participants

Participants (n = 315) were recruited for this study over an 18 month period. Participants were aged between 18-65 years (mean = 38.28 years) and 54.9% were female. The recruitment of participants was from three main community populations; (a) business population, (b) community population and (c) university (staff and student) population. Participants were invited to participate in the study if they were of working age (18 years – 65 years). Demographic characteristics of participants is shown in Table 4. Participants were required to be English literate with the ability to utilise computer-based equipment.

Table 4 - Demographic characteristics of participants in Study One

		N	%
Recruitment	Business	162	51.4
	Community	96	30.5
	Student	57	18.1
Gender	Male	142	45.1
Relationship	Single	92	29.2
	Married	152	48.3
	Divorced	14	4.4
Age (years)	18-25	65	20.6
	26-35	89	28.3
	36-45	58	18.4
	46-55	68	21.6
	56-65	35	11.1
Employment	Employed	193	61.3
	Unemployed	88	27.9
	Student	33	10.5

4.4. Recruitment

The recruitment process was specific to each of the three community populations. Gaining access to the populations was also a significant element of the recruitment process and relationships were ongoing throughout the 18-month recruitment period.

4.4.1. Business population

Initial contact was first made with management of a city centre multi-business tower in the North-West of England. Contact for to the individual businesses housed in the business tower was made via emails which succinctly explained the intentions of the study. If a business was interested in taking part in the study, a follow up call to the appropriate business lead was carried out explaining the study in lay terms, ensuring full clarification and a true understanding of an individual's participation in the study. This led to initial face-to-face meetings with members of management and departmental leads from each of the interested parties. It was decided that for the recruitment of the business sample it would not be feasible for the research to be onsite recruiting in a face-to-face capacity. It was negotiated that an email would be best suited to this sample. An email was composed and first vetted by the 'Head of Operations'; before being put onto the internal intranet system where employees could see all the information and get in touch in their own time. If willing to participate the email clearly stated that participants should contact the researcher via email or by phone. If interested in the study each prospective participant would be emailed the information sheet to read and would be given at least one week to decide whether to take part. The researcher would meet participants and conduct the research in a conference room ensuring privacy was provided to all of those who wished to take part in the study.

4.4.2. Community population

Initial contact was made with the manager of two Northern town community centres. As with the business population, full clarification was provided at the centres and management were clear what the researcher intended to do. Each of the interested community centres agreed to provide a space to administer the study. Within these centres, participants were approached in person whilst attending group events/activities e.g. mothers and toddlers, coffee mornings, art groups. There were a number of community events which were held at the same time each week. The researcher went in person to these events and spoke briefly about the study to the groups and individuals within the centres. Those who showed an interest in the study were given an information sheet to take home and read. They were told that if they would like to take part then the researcher would be at the centre the following week to answer any queries and arrange an appropriate time for their participation. The researcher would meet participants and conduct the research in private office rooms which were provided by the community centres.

4.4.3. Student/staff population

The student population was made available to the researcher due to departmental contacts. All students were recruited on the University of Central Lancashire (UCLan) campus. The UCLan student population were recruited via the psychology SONA system. This system allows students to view current research projects and in exchange for their participation they would gain points, allowing students access to use the system during their undergraduate third year projects. Participant information about the study was made available via this system. UCLan students as well as employees were recruited in person by the researcher. They were approached at their place of work, given brief verbal details and provided with an information sheet. Those interested in participating were asked to contact the researcher via the contact details provided to answer any queries. Once interested parties had read the information sheet and any questions had been answered, a suitable time for their involvement in the study was arranged. Participants that were willing to take part on the day were consented and escorted to the private assessment room by the researcher. Those participants which were consented at a later date were given detail of the location of the assessment room. If participants were unable to find the assessment room, they were directed to contact the researcher to arrange a convenient place to meet and be escorted to the room.

4.5. Self-Report Materials

4.5.1. Demographic information and Clinical variables

Data from each participant were collected concerning clinical and demographic information. This was achieved via the completion of a questionnaire shown in Appendix 2. A range of clinical variables was collected with many associated with both elevated weight and cognitive dysfunctions (Hauner et al., 2017; 2005; Jiang et al., 2016). These included diabetes, heart disease, asthma/lung disease, stroke, high blood pressure and high cholesterol. The demographic information collected included age, gender, employment and postcode.

4.5.2. Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977)

The Center for Epidemiological Studies-Depression (CES-D) Scale was used to measure depression and has been used in screening for depression in research and clinical settings (Vilagut et al., 2016). The CES-D was included to monitor depression in the research sample as past research has highlighted when levels of depression in obesity are high, individuals appeared to perform worse on tests of executive function (Restivo et al., 2017). It is composed of 20-item questions, which measure depression symptoms in four domains (factors): Depression Affect, Somatic Complaints/Activity Inhibition, Positive Affect, and Interpersonal Difficulties (see Appendix 3). Participants were instructed to complete the CES-D form by indicating how often they experienced each symptom in the past week. The response is a four-point scale ranging from 0 to 3 indicating the frequency: 'rarely or none of the time, or less than one 1 day,' 'some or little of the time, or 1–2 days,' 'occasionally or a moderate amount of the time, or 3–4 days,' and 'most of the time or 5–7 days,' except for questions 4, 8, 12, and 16, for which the scale is reversed. The score is the sum of the 20 questions (possible range 0-60) with higher total scores indicating worse depressive symptoms. If an individual has a score of 16 or more they are considered to be depressed. For the four factors (domains), higher factor scores indicate worse depression symptoms other than the domain 'Positive Affect.' The scale has been validated in a non-clinical sample and it was found to demonstrate good internal consistency (α=.86) and adequate test-retest reliability (r=.85) (Miller et al., 2008).

4.6. Weight and Height Measurements

4.6.1. Weight Measure

Weight was taken using Tanita Digital Medical Scales. Participants were asked to remove shoes, heavy jewellery, and heavy outer garments such as cardigans and jackets. Measurement was obtained with the participant standing with feet together in the centre of the scale with their arms by their sides and head facing forward. Prior to participants stepping on to the scale, the scale was turned on and checks were made to ensure that the scale was at '0'. Weight was recorded to the nearest 0.1kg.

4.6.2. Height Measure

Height was obtained using a stadiometer (a device with a sliding head plate, a base plate and back plate with measuring scale). With shoes removed, the participant was requested to stand on the centre of the base plate, feet together and heels against the rod. The participant's back was positioned as straight as possible against the rod with their arms by their sides. With the participant facing forwards, and the head at right angles to the chest, they were instructed to breathe in deeply and to stretch to their fullest height. The head plate was positioned into the participant's head, and a measurement taken. Height was recorded to the nearest 0.1cm.

From the measurements of weight and height, Body Mass Index (BMI) was calculated as a ratio of weight (kg) to height (m) squared. BMI was classified using the WHO BMI groups (kg/m^2; underweight BMI < 18.5; normal weight BMI 18.5 - 24.9; overweight BMI 25.0 – 29.9; class I obesity BMI 30.0 – 34.9; class II obesity BMI 35.0 – 39.9; class III obesity BMI > 40.0).

4.6.3. Waist Circumference Measure

Waist circumference was measured using a tape measure. Participants were requested to stand up straight and to refrain from holding their breath or breathing in. The waist was measured round from the location of the top of the hip bone, ensuring that the tape measure was positioned horizontally, parallel to the floor. Waist circumference is measured in cm.

Waist circumference was classified using the National Institute for Health and Clinical Excellence (NICE) recommended waist circumference cut-off points associated with disease risk: no increased risk, increased risk, high risk, very high risk.

4.6.4. Behavioural / Performance Based Cognitive Tests

The conventional measure of executive function has often been based on behavioural cognitive tests (Pennington & Ozonoff, 1996). Performance-based tests provide a level of standardisation and control which allows for the presentation of material to be monitored so that each participant completes the task in precisely the same way as other participants. The measurement of performance allows for robust quantitative data with dependent variables based on response times and / or error rates (Toplak et al., 2013).

The work for this thesis took place outside of a laboratory or clinical setting, and therefore many factors had to be considered when deciding which cognitive tests would be most appropriate. The main obstacle to overcome was the limited time available with each participant as individuals were attending community centre activities or participating during their working hours. A long cognitive test battery would not have been appropriate and would likely have resulted in low recruitment numbers. In order to collect a robust amount of data to account for each of the executive functions it was necessary to use tasks which could be completed in a short amount of time. Alongside this, business employers who were allowing their staff the opportunity to take part in the studies would permit only forty minutes to complete the study. The total amount of time to participate in the studies had to account for the cognitive test battery, consenting procedures and self-reporting questionnaires. With this in mind, each cognitive task would have to be completed in a maximum of six minutes.

Participation in the study took place at multiple sites adding to the complexities of the methodology. In a laboratory setting the environment can be controlled and equipment set up to complete a whole range of tests. As well as cognitive test apparatus the researcher was also required to transport a full set of weighing scales and a stadiometer across different locations. Taking this into account the choice and set-up of equipment for cognitive testing had to be simplistic, with the use of only a laptop and paper tests to record data.

The theoretical standpoint of executive function by Miyake et al. (2000) underpins this work. Each of the Miyake cognitive test battery tasks were assessed, and considerations were made about the following: ease of programming, testing time length, equipment requirement, set up time, test accuracy and test stimuli (step by step considerations to be found in Appendix 4).

The following cognitive tests were chosen to indicate the three target executive functions; inhibition, updating, shifting. A complex task was also included with the expectation that this would load on to more than one executive function.

4.6.5. Inhibition Task - Stroop Task (Stroop, 1935)

Overview. The Stroop task or Stroop Colour and Word Tests (SCWT) (Stroop, 1935) is a known test of the executive function inhibition, to control automatic and prepotent responses. This task requires the ability to suppress or override the more dominant response. In this task, adapted for computer administration, participants were instructed to correctly choose the name of the colour of a stimulus as quickly as possible in each trial, with reaction times measured by correctly identifying the target colour. The task included the completion of four tests using the following visuals:

i.) A string of symbols (e.g. Xs) printed in one of four colours (red, green, blue or purple)

ii.) Name of the colours printed in black

iii.) Colour words printed in a different colour where the name of the colours had to be correctly identified (e.g., the word BLUE printed in red correctly identified as blue) iv.) Colour words printed in a different colour where the colour of the text had to be correctly identified (e.g., the word BLUE printed in red correctly identified as red).

The dependent measure was the reaction time difference between the trials in which the word and the colour were incongruent (i.e. a word designates one colour and is printed in a different colour) and the trials that consisted of congruent symbols / words (i.e. the word or symbols were clearly associated with one colour only). A quicker score indicates better cognitive performance.

Materials. The full experiment was executed using E-Prime 2.0 software (Psychology Software Tools, 2012) on a laptop with 15.6-inch screen and 1920 x 1080 pixel resolution. Four keys on the laptop keyboard were covered using coloured stickers to represent the Stroop task colour choices.

Consideration. This was a quick task which meant that even the slowest participants would complete the task within the six-minute timeframe. The task required the addition of coloured keys to provide responses, but these were pre-installed prior to testing so this did not increase set-up time. An additional reflection was the usefulness of this task in comparison to other studies of executive function. The Stroop task is a common task and implemented regularly in research looking into executive function and it will be easier to highlight, find norms and provide details on how the participants performed in comparison to other studies.

Procedure. Participants were verbally instructed by the researcher to the significance and position of the coloured key on the laptop. An initial instruction slide was presented on the laptop screen shown in Figure 4. The task required the participant to perform in four blocks of 20 trials, each separated by an instruction interval directing the participant to which of the four visual tasks they would be completing. Participants initiated a trial by pressing the spacebar. A single visual stimulus from one of the four tasks would be presented on the screen. At this indication, participants were required to respond using the coloured buttons on the laptop keyboard. When the participant had responded, the next stimulus would then appear on the screen. A black screen signified the end of the task.

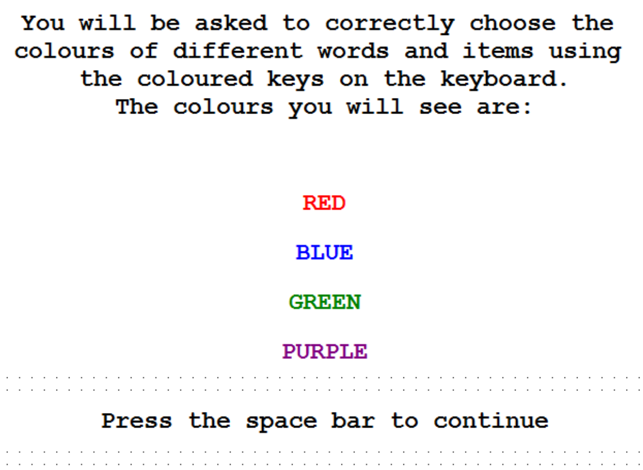

Figure 4 – E-Prime instruction visual for The Stroop Task

4.6.6. Shifting Task - Local-Global Task (Navon, 1977)

Overview. The Local-Global task (Navon, 1977) is a known test of the executive function shifting, requiring the cognitive flexibility to switch between mental sets (Miyake et al., 2000). This task involves the continuous disengagement of an irrelevant task rule and the active engagement of a relevant task rule. In the task, a figure, known as a Navon figure, in which the shape of the ‘’global’’ figure (e.g., the letter ‘E’) were composed of much smaller, ‘’local’’ figures (e.g., the letter ‘A’), were presented on the computer screen. Participants were required to complete two different tasks. In the first task, participants were instructed to choose the letter which represented the “global”, overall figure. Whilst in the second task, participants were instructed to choose the letter which represented the “local”, smaller figures. The instructions changed across successive trials and the participants were required to shift from examining the local features to the global features or vice versa. Reaction times were recorded for each of the trials. The shift cost was then calculated as the difference between the average reaction times for the trials requiring a shift in mental set ‘conflicting’ (i.e., instruction changing from local to global or vice versa) and the trials in which no shift was required ‘consistent’ (i.e., instructions remained the same). A quicker average score indicates better cognitive performance.

Materials. The full experiment was executed using E-Prime 2.0 software (Psychology Software Tools, 2012) on a laptop.

Consideration. This task could be completed within the six-minute time limit, accounting for those who took an excessively long time to complete each trial. This task only required the use of a laptop and required no additional equipment set-up time.

Procedure. The task required the participant to performed one block of 24 target trials, each separated by an instruction interval instructing the participant if they were to choose the “global” or “local” figure with an exemplar shown in Figure 5. Participants initiated a trial by pressing the spacebar. The “global” figure made up of “local” figures then appeared on the screen. At this indication, participants were then required to respond using the letters on the laptop keyboard. When the participant had responded, the next trial instruction screen appeared on the screen. A black screen signified the end of the task.

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You will see letters made up of other letters and be asked to choose either the large
letter (GLOBAL level) or the letters that comprise it (LOCAL level).
For instance,

AAAAAA
A
A
AAAAAA
A
A
AAAAAA

would be an "A" at the LOCAL level, or an "E" at the GLOBAL level.

Please press the space bar to continue
```

Figure 5 – E-Prime instruction visual for The Local-Global Task

4.6.7. Updating Task - Keep-Track Task (adapted from Yntema, 1963)

Overview. The Keep-Track task (adapted from Yntema, 1963) is a known test for the executive function updating, the ability to continually monitor and update information in working memory (Miyake et al., 2000). This task requires the active manipulation of task-relevant information in working memory, rather than the passive storing of this information. In each trial participants were shown multiple target categories prior to the presentation of fifteen words, including 2 or 3 exemplars from each of six possible categories; animals, colours, countries, lessons, sports, and relatives. The categories and affiliated words are shown in Table 5. The task was to remember the last word presented in each of the target categories and then write down these words at the end of the trial. For example, if the target categories were colours, relatives, and countries, then, at the end of the trial, participants recalled the last colour, the last relative, and the last country presented in the list. Participants had to closely monitor the words presented and update their working memory representations for the appropriate categories when the presented word was a member of one of the target categories. Before this task began, participants saw all six categories and the exemplars in each to ensure that they knew to which category each word belonged and then practiced on a single trial with three target categories. The proportion of words recalled correctly was the dependent measure, a higher score indicating better cognitive updating performance.

Table 5 – Category and Word List for the Keep-Track Task

Animals	Colours	Countries	Relative	Sports	Lessons
Horse	Black	Italy	Mother	Football	History
Sheep	Yellow	France	Father	Rugby	Drama
Mouse	Orange	Spain	Sister	Tennis	Maths
Tiger	White	England	Brother	Hockey	Science
Rabbit	Purple	Germany	Uncle	Running	Music
Monkey	Brown	Holland	Cousin	Cricket	Art

Materials. The visual stimuli were presented using E-Prime 2.0 software (Psychology Software Tools, 2012) on a laptop. This is a pen and paper behavioural task.

Consideration. This task could also be completed with a six-minute time limit, accounting for those participants who took a longer than expected time to recall the target word. This task also introduced 'word' stimuli which is an alternative from the letter and number exemplars which are regularly used.

Procedure. Prior to the task, participants were shown on screen all the potential categories and the exemplars associated with each category. The task began with one practice trial performed prior to the block of 5 experimental trials. The instructions proceeding each trial were shown in Figure 6 with the names of the target categories. Participants initiated a trial by pressing the spacebar. Fifteen words were presented serially and for 1500ms apiece, immediately after the presentation of the last word in each trial, the names of the target categories reappeared. At this indication, participants were required to write down the words they had remembered to be the last in those categories. Unlimited time was given to recall. When the participant had completed the trial, the next trial began by pressing the spacebar. Participants performed two trials with three target categories and three with four target categories. A black screen signified the end of the task.

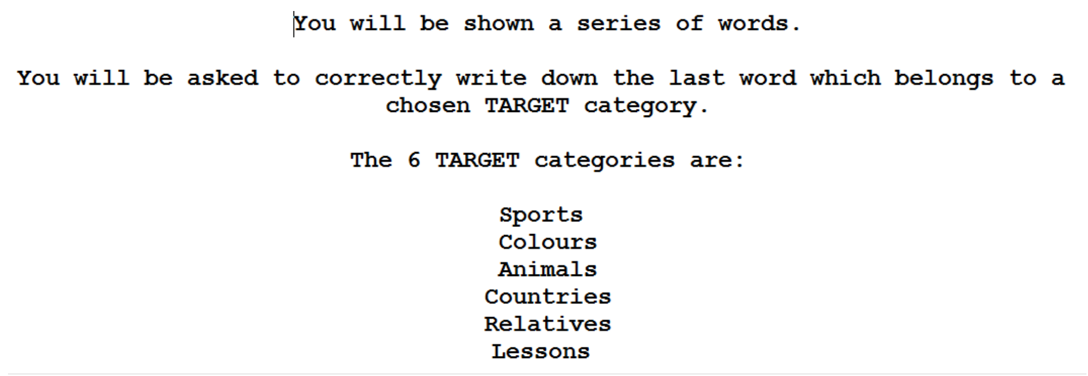

Figure 6 – E-Prime instruction visual for The Keep-Track Task

4.6.8. Complex Task - Random Number Generation (adapted from Towse and Valentine, 1997)

Overview. The task number random generation explores executive function performance through the ability to generate random sequences of digits (adapted from Towse and Valentine, 1997). For success, this task requires a number of high level processes, including the ability to retain task instructions in working memory, updating short term sequences in working memory, switching information purposely and actively to produce a randomised sequence (Ginsberg and Karpuik, 1994; Peters et al., 2007). To demonstrate the concept of randomness, the participants were given the analogy of picking a number out of a hat, reading it out loud, putting it back, and then picking another. The valid responses generated during were analysed using Towse and Neil’s (1998) RgCalc program, which produces many different indices that have been commonly used in the analysis of ‘‘randomness.’’ The measure that was derived from the data is the mean repetition gap (Mean RG), a measure obtained by counting the number of gaps between two identical digits (Peters et al., 2007) This measure provides a quantitative measure of repetition performances (Towse, 1998) with higher score indicates better cognitive performance.

Materials. The instructions and audio elements of the experiment were executed using E-Prime 2.0 software (Psychology Software Tools, 2012) on a laptop.

Considerations. This was a task that required limited set up and could be completed within the six-minute time limit. It was an easy task to programme and simple for participants to understand. This task introduced a numerical stimulus which was not yet represented by the other tasks.

Procedure. The task began with one practice trial performed prior to a test block. An initial instruction visual was presented on the laptop screen shown in Figure 7. Participants initiated the trials by pressing the spacebar. At this indication, participants heard a computer-generated beep every 1000ms. They were required to read aloud a number from 1 to 9 for each beep so that the string of numbers would be in as random an order as possible and maintaining a consistent response rhythm led by the beep. During the practice trial participants responded to 10 beeps and through the experimental trial participants responded to 70 beeps. The researcher noted down each of the participants responses. A black screen signified the end of the task.

You will now repeat the task.

For each beep say out loud a randomly chosen number between 1 and 9. Please try to maintain a constant rhythm.

Imagine you have pulled the number out of a hat, read it out loud and put it back in again.

Please press the space bar to start.

Figure 7 – E-Prime instruction visual for The Random Number Generator

4.7. Procedure

Participants were tested individually in appropriate rooms located at each of the recruitment sites. A brief overview of the experimental procedure was provided, as was an opportunity for the participant to ask questions. Informed written consent was obtained from all participants. Data was then collected concerning demographic information and a range of clinical variables. Weight and height were then taken. To control for depression, the CES-D was randomly assigned to be completed before or after the behavioural cognitive tests. Participants were seated in front of a laptop screen and were informed that all the instructions for each of tasks they were about to undertake would be presented on the computer screen. All participants completed the Keep-Track task, Local-Global task, Stroop task and Random Number Generation. It is theorised that there is an overlap of the executive functions that these cognitive tests are tapping into. With more practice this may lead to potential enhanced performance as more tests are completed. To account for this the order of these tasks were randomised as shown in Figure 8. The researcher set up each task on the laptop and then returned to a location in the room where they were not visible to the participant. This set-up time also served as a check that the participant understood each task and also provided the opportunity for the participant to ask any further questions.

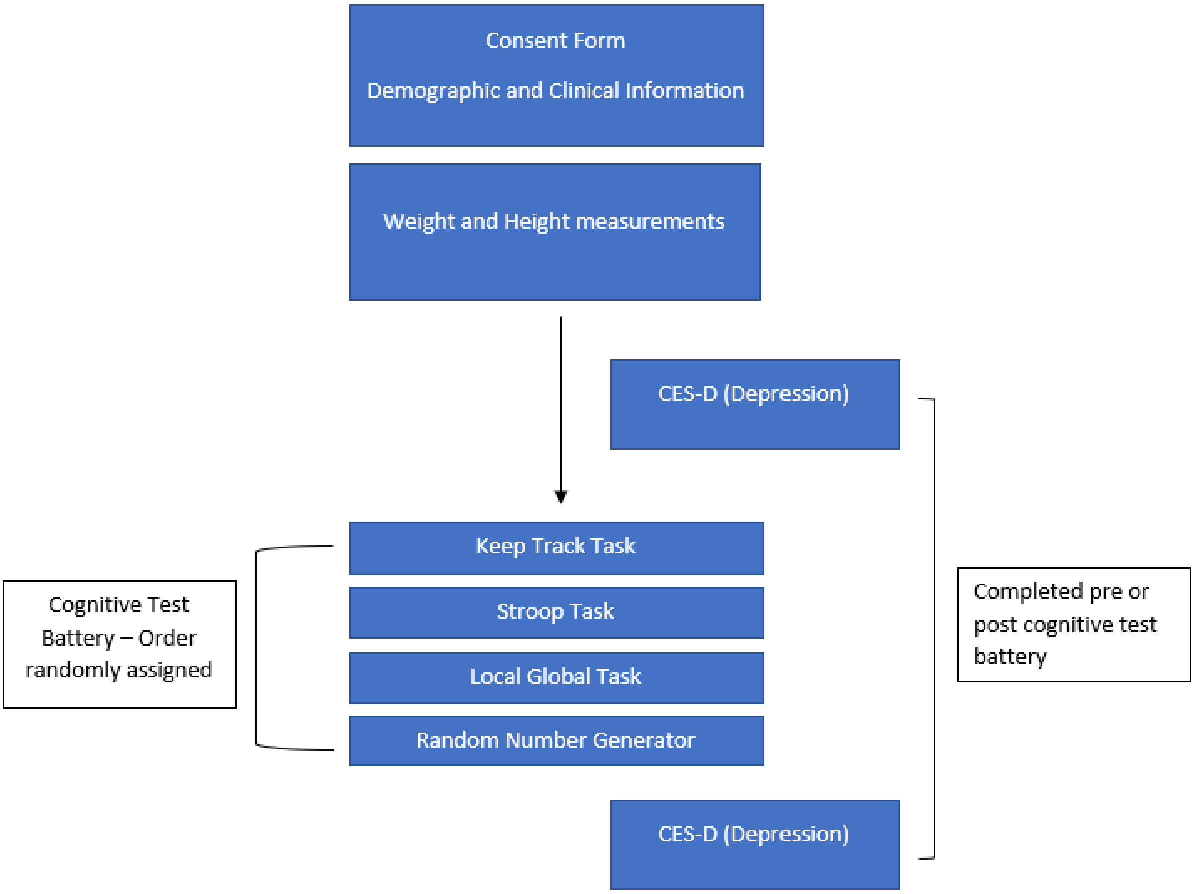

Figure 8 - Flow chart of Study One procedure

4.8. Database Management and Data analysis

All analyses were conducted using IBM SPSS Version 25. All data which were collected were checked for discrepancies and the outputs from computer programmes were examined. Variables were appropriately coded where necessary.

Quantile regression analyses were conducted to assess the extent to which the key study variables predicted cognitive test performance whilst adjusting for the effects of variables known to effect performance. Quantile regressions require no assumptions to be met and therefore no pre analysis to assess the prevalence of missing data and deviations from normality were required.

Quantile regressions, as depicted by Koenker (1978), provide an insight into the relationship of independent variables with a conditional quantile of a dependent variable. This regression technique allows an insight into performance across the quartiles rather than a standard regression where there is reliance on the mean to determine an association (Waldmann, 2018). Compared to a mean regression with a single linear equation, a quantile regression can predict the median, the upper quartile and the lower quartile with a different linear equation for each. This technique can provide much more information about the effect of the predictors on the outcome. Quantile regressions can also allow for the violations of the assumptions for mean regressions such as outliers and for data which does not follow the normal distribution (Waldmann, 2018).

This statistical model is regularly used by ecologists and biologists and in recent years, due to the above advantages, there has been an increase in its use (Cade and Noon, 2003). It has been suggested that areas of psychology including the study of cognition which regularly encounters problems with data distribution such as normality violation would benefit from utilising an alternative to a means regression. In addition to this, by producing a means-based effect via mean regressions, it has been proposed that other associations in the data may be lost (Petscher and Logan, 2014). Furthermore Sherwood et al. (2016) found that estimating conditional percentiles for neuropsychological tests using mean regressions was not adequate, concluding that the quantile regression method was more robust and had the potential to be useful in monitoring and flagging cognitive decline. Petscher and Logan (2014) view the use of a quantile regression model as an opportunity to expand the scope of a research question from the linear regression

‘What is the relation between X and Y?’ to the quantile extension ‘For whom does a relation between X and Y exist?’ This statistical model has the potential to provide much more information about the effect of the predictors on the outcome.

The results presented will be for the four cognitive tests (Random Number Generator, Local-Global Difference, Stroop Difference, Keep-Track Score) in relation to the six WHO BMI’s (underweight, normal weight, overweight, obese class I, obese class III, obese class III). Adjusted data will be presented with age, depression and gender been included in the analysis in Table 8, 9 and 10. Gender was represented by the female indicator for the male and female tests. No indicators were used when analysing the gender individually. Age was represented by the ’46 +’, the median score for the group. Depression was represented by an indicator representing those above a threshold and indicating subthreshold depressive symptoms. The unadjusted data can be found in Appendix 5, 6 and 7. The importance of adjusting for known impacted variables is supported by this data as important differences would have been missed.

The correlations (Kendall tau-b) will also be presented between the BMI groups and the 4 cognitive tests.

4.9. Results

Table 6 reports the demographics and self-reported health status among the participants. Table 7 reports on the means and standard deviations across all of the BMI groups for each of the cognitive test scores (Random Number Generator, Local-Global Difference, Stroop Difference, Keep-Track Score.)

Similar mean scores were found across the BMI groups in the random number generation task. The Keep-Track task means highlighted that underweight participants remembered fewer words than the other groups. Notable differences were found in the

Local-Global task and Stroop task with the underweight and the obese class III groups responding slower and therefore performing worse across both tasks.

Table 6 – Health Status of Participants

		N (%)
WHO BMI category		
	Underweight (<18.5 kg/m^2)	39 (12.4%)
	Normal weight (18.5 – 24.9 kg/m^2)	108 (34.3%)
	Overweight (25.0 – 29.9 kg/m^2)	57 (18.1%)
	Obese class I (30.0 – 34.9 kg/m^2)	53 (16.8%)
	Obese class II (35.0 – 39.9 kg/m^2)	30 (9.5%)
	Obese class III (40.0> kg/m^2)	28 (8.9%)
Waist Circumference Category[1]		
	No increased risk	145 (75.1%)
	Increased risk	11 (5.7%)
	High risk	9 (4.7%)
	Very high risk	28 (14.5%)
Self-Reported measures		
	Diabetes	7
	Heart disease	6
	Asthma/Lung disease	19
	Stroke	0
	High blood pressure	10
	High Cholesterol	4
	CES-D[2]	32 (10.2%)

[1]WHO recommended thresholds to determine an individual's relative risk of obesity-related ill health

[2]Score of 16 or over indicating subthreshold depressive symptoms

Table 7 - Means and SD of the cognitive tests by BMI class and gender

		Random Number Generator[1]		Local-Global Difference[2]		Stroop Difference[3]		Keep-Track Score[4]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Underweight									
	Total n=39	7.60	.91	707.13	684.06	554.02	683.11	7.62	4.41
	Male n=15	7.50	.88	506.81	569.63	529.29	640.89	8.13	4.10
	Female n=24	7.66	.93	832.33	730.13	575.97	721.16	7.29	4.65
Normal weight									
	Total n=108	7.52	.91	302.79	721.11	330.48	693.35	9.81	3.61
	Male n=54	7.37	.96	215.33	775.60	438.30	709.46	10.59	3.32
	Female n=54	7.67	.84	391.89	656.38	222.67	665.97	9.02	3.77
Overweight									
	Total n=57	7.34	.94	264.28	663.71	336.71	639.79	10.47	3.61
	Male n=29	7.31	.93	373.19	713.56	461.43	636.25	10.83	3.81
	Female n=28	7.36	.97	147.31	596.76	207.53	628.63	10.11	3.41
Obese Class I									
	Total n=53	7.19	1.01	294.73	638.11	338.14	583.97	10.36	3.35
	Male n=18	6.85	1.08	282.18	553.09	403.32	496.96	10.22	3.41
	Female n=35	7.36	.94	301.19	685.33	304.62	628.22	10.43	3.36
Obese Class II									
	Total n=30	7.37	1.03	196.90	487.19	307.56	669.92	8.90	3.99
	Male n=15	7.48	.84	235.46	522.45	212.25	578.80	8.40	4.78
	Female n=15	7.27	1.21	158.34	464.24	402.87	812.59	9.40	3.11
Obese Class III									
	Total n=28	7.29	.96	925.67	913.62	925.95	934.83	8.32	4.44
	Male n=11	7.22	1.04	517.85	766.60	904.56	807.63	7.55	4.53
	Female n=17	7.34	.95	1189.58	923.53	940.65	1038.92	8.82	4.45

[1] A high score = better performance. [2]Local-Global Difference = Local-Global Conflicting - Local-Global Consistent. A high score = slower performance.

[3] Stroop Task Difference = Stroop Incongruent – Stroop Congruent. A high score = slower performance. [4] A high score = better performance.

4.10. Adjusted results

For all of the quantile regression results comparisons were against the normal weight scores. Regression results are provided for male only, female only and gender combined data across three quantiles; lower, median and upper. Quantile regression scores can be found in tables 10, 11 and 12.

Each of the tables include the BMI estimates, standard error values, 95% confidence intervals and p-values. Data is presented for males only, females only and total sample data. Table 8 shows the adjusted quantile regressions scores for the lower quartile across all four of the cognitive measures. Table 9 shows the adjusted quantile regressions scores for the median quartile across all four of the cognitive measures. Table 10 shows the adjusted quantile regressions scores for the upper quartile across all four of the cognitive measures.

4.10.1. Random Number Generator

Quantile regression results for the Random Number Generator cores revealed that the obese class III group perform significantly worse for males ($F(132)=-2.16$, $p=.033$) with better test performance demonstrated by the underweight and overweight males groups ($F(132)=2.42$, $p=.017$; $F(132)=2.05$, $p=.043$). For females, a reduced performance is also seen in overweight, obese class I and obese class II individuals ($F(165)=-2.19$, $p=.030$; $F(165)=-2.27$, $p=.019$; $F(165)=-2.93$, $p=.004$). Median results showed significantly impaired obese class I performance, specifically highlighted in the male only data ($F(132)=-2.62$, $p=.010$). Whilst the female only results showed a significantly poorer performance in the overweight and obese class III groups ($F(165)=-2.25$, $p=.025$; $F(165)=-2.50$, $p=.013$). The upper quartile results revealed no differences between the groups. Overall, across the lower and median quartiles, females who were classified as obese (I, II & III) performed significantly worse compared to the other weight groups whilst completing a complex task, showing a limited capacity to generate numbers randomly. This was mirrored in males with obese classes I and III.

4.10.2. Local-Global Task

The Local-Global difference scores for the lower quartile show that reduced performance was shown in the obese class III groups for both the combined data ($F(303)=1.98$, $p=.049$) and was also recognised in the female only dataset ($F(163)=2.60$, $p=010$). The overweight groups performance was better for lower quartile scores for females ($F(163)=-2.26$, $p=.025$). The median and upper quartile results revealed for the combined data that the underweight (median: $F(303)=2.00$, $p=.046$; upper: $F(303)=2.21$, $p=.028$) and obese class III (median: $F(303)=3.16$, $p=.002$; upper: $F(303)=3.00$, $p=.033$) groups significantly underperformed. This was also represented in the female only data (underweight median: $F(163)=2.27$, $p=.025$; underweight upper: $F(163)=3.33$, $p=.001$; obese III median: $F(163)=3.64$, $p<.001$; obese III upper: $F(163)=4.1$, $p<.001$). With the addition of the upper quartile results for the male only data indicating that the obese class III group were also at a significant disadvantage ($F(133)=2.29$, $p=.024$). Overall, across the quantiles and the gender groups the underweight and obese class III groups performed significantly worse on this task, responding slower to inconsistent stimuli.

4.10.3. Stroop Task

The Stroop difference score for the combined data reveals slower and poorer performance for the obese class III group across the quartiles (lower: $F(304)=2.30$, $p=.022$; median: $F(304)=4.70$, $p<.001$; upper: $F(304)=4.74$, $p<.001$) and this is reflected in the female only data (lower: $F(164)=2.46$, $p=.015$; median: $F(164)=3.59$, $p<.001$; upper: $F(164)=3.25$, $p=.001$). The obese class III group only revealed significant results for the upper quarter male only scores ($F(133)=3.93$, $p<.001$). The results also revealed that the underweight group had difficulties with this test with lower quartile combined data revealing that performance was significantly slower (F(304)=2.27, p=.024) and across the median scores male and female only data also suggested this (F(133)=2.30, p=.023; F(164)=1.98, p=.050). Overall, across the quantiles and the gender groups the obese class III group performed significantly worse on this task, responding slower to inconsistent stimuli.

4.10.4. Keep-Track Task

The Keep-Track scores revealed that across the data for the lower quartile scores performance was significantly worse for the underweight group (combined: F(305)=-4.34, p<.001; male: F(133)=-4.03, p=<.001; female: F(165)=-2.80, p=.006). The obese class II and III groups also showed a poorer performance for the male only data (male: F(133)=-4.03 , p=<.001; male: F(133)=-2.87, p=.005) with a similar significant performance in the obese class III group for the combined data (F(305)=-2.87, p=.004). The obese class III group also performance significantly worse for the combined data median scores (F(305)=-2.89, p=<.004) with the overweight group revealing a significantly better performance (F(305)=2.49, p=.013). Overall, the underweight and the class III obese groups performed significantly worse on this task, recalling less words than the other weight groups.

Table 8 - Adjusted quantile regressions of the lower quartile for the four cognitive measures

	Total n=315					Males only n=142					Females only n=173				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	6.75	0.19	6.37	7.13	0.000	6.50	0.16	6.19	6.81	0.000	7.25	0.22	6.81	7.69	0.000
Underweight	0.50	0.31	-0.11	1.11	0.105	0.75	0.31	0.14	1.36	0.017	-0.64	0.36	-1.35	0.07	0.075
Overweight	-0.25	0.27	-0.78	0.28	0.356	0.50	0.24	0.02	0.98	0.043	-0.75	0.34	-1.43	-0.08	0.030
Obese Class I	-0.50	0.28	-1.04	0.04	0.072	-0.50	0.29	-1.07	0.07	0.084	-0.75	0.32	-1.38	-0.13	0.019
Obese Class II	-0.25	0.35	-0.93	0.43	0.470	0.00	0.32	-0.63	0.63	1.000	-1.25	0.43	-2.09	-0.41	0.004
Obese Class III	-0.25	0.35	-0.94	0.44	0.474	-0.75	0.35	-1.44	-0.06	0.033	-0.53	0.41	-1.33	0.27	0.195
Age (46+)	-0.25	0.20	-0.65	0.15	0.218	0.00	0.21	-0.41	0.41	1.000	-0.25	0.24	-0.72	0.22	0.292
Gender (Female)	0.00	0.19	-0.38	0.38	1.000										
Depression	0.44	0.32	-0.18	1.06	0.163	0.00	0.39	-0.78	0.78	1.000	0.39	0.33	-0.26	1.04	0.236
Local-Global Difference															
Intercept	-78.50	77.97	-231.93	74.93	0.315	-143.91	95.98	-333.75	45.93	0.136	-0.08	84.00	-165.96	165.80	0.999
Underweight	186.67	124.05	-57.43	430.77	0.133	215.11	187.63	-156.02	586.24	0.254	140.08	135.34	-127.17	407.33	0.302
Overweight	-121.73	109.88	-337.95	94.49	0.269	11.21	148.18	-281.88	304.30	0.940	-297.62	131.67	-557.61	-37.63	0.025
Obese Class I	-50.34	111.73	-270.21	169.53	0.653	118.65	174.03	-225.58	462.88	0.497	-203.14	120.10	-440.29	34.01	0.093
Obese Class II	-107.46	137.35	-377.74	162.82	0.435	-244.81	187.63	-615.94	126.32	0.194	-154.05	161.43	-472.82	164.72	0.341
Obese Class III	278.32	140.73	1.39	555.25	0.049	89.53	210.73	-327.29	506.35	0.672	400.70	153.86	96.88	704.52	0.010
Age (46+)	-2.92	81.60	-163.49	157.65	0.971	-125.68	123.08	-369.13	117.77	0.309	3.93	89.82	-173.43	181.29	0.965
Gender (Female)	31.83	77.15	-119.98	183.64	0.680										
Depression	153.66	128.81	-99.82	407.14	0.234	429.04	237.68	-41.08	899.16	0.073	122.60	126.30	-126.80	372.00	0.333
Stroop Difference															
Intercept	4.36	58.03	-109.84	118.56	0.940	16.11	84.90	-151.82	184.04	0.850	-143.27	66.66	-274.89	-11.65	0.033
Underweight	209.87	92.29	28.25	391.49	0.024	16.22	165.98	-312.09	344.53	0.922	209.87	107.51	-2.41	422.15	0.053
Overweight	90.04	81.16	-69.66	249.74	0.268	-6.51	131.08	-265.78	252.76	0.960	92.20	102.82	-110.83	295.23	0.371
Obese Class I	16.09	83.09	-147.42	179.60	0.847	4.34	153.95	-300.17	308.85	0.978	1.89	95.28	-186.25	190.03	0.984
Obese Class II	-112.65	102.23	-313.82	88.52	0.271	-105.57	165.98	-433.88	222.74	0.526	-126.48	128.37	-379.96	127.00	0.326
Obese Class III	244.61	106.20	35.63	453.59	0.022	152.54	186.42	-216.18	521.26	0.415	307.81	125.16	60.69	554.93	0.015
Age (46+)	42.45	60.67	-76.93	161.83	0.485	30.70	108.88	-184.66	246.06	0.778	55.02	71.14	-85.46	195.50	0.440
Gender (Female)	-147.63	57.45	-260.68	-34.58	0.011										

Depression	-65.21	94.65	-251.47	121.05	0.491	93.50	210.25	-322.37	509.37	0.657	-65.21	98.65	-260.00	129.58	0.510
Keep-Track															
Intercept	8.00	0.58	6.86	9.14	0.000	9.00	0.63	7.75	10.25	0.000	8.00	0.89	6.25	9.75	0.000
Underweight	-4.00	0.92	-5.82	-2.19	0.000	-5.00	1.24	-7.45	-2.55	0.000	-4.00	1.43	-6.82	-1.18	0.006
Overweight	1.00	0.81	-0.60	2.60	0.219	0.00	0.98	-1.94	1.94	1.000	1.00	1.37	-1.70	3.70	0.466
Obese Class I	1.00	0.83	-0.63	2.63	0.229	-1.00	1.15	-3.27	1.27	0.386	2.00	1.27	-0.50	4.50	0.116
Obese Class II	0.00	1.02	-2.01	2.01	1.000	-5.00	1.24	-7.45	-2.55	0.000	1.00	1.71	-2.37	4.37	0.559
Obese Class III	-3.00	1.05	-5.06	-0.94	0.004	-4.00	1.39	-6.75	-1.25	0.005	-3.00	1.63	-6.21	0.21	0.067
Age (46+)	-2.00	0.61	-3.19	-0.81	0.001	-1.00	0.81	-2.61	0.61	0.221	-2.00	0.95	-3.87	-0.13	0.036
Gender (Female)	0.00	0.57	-1.13	1.13	1.000										
Depression	-1.00	0.95	-2.86	0.86	0.291	-2.00	1.57	-5.11	1.11	0.205	0.00	1.31	-2.59	2.59	1.000

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Table 9 - Adjusted quantile regressions of the median quartile for the four cognitive measures

	Total n=315					Males only n=142					Females only n=173				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	7.25	0.17	6.91	7.59	0.000	7.25	0.21	6.83	7.67	0.000	8.00	0.22	7.57	8.43	0.000
Underweight	0.20	0.27	-0.34	0.74	0.466	0.59	0.41	-0.22	1.40	0.153	0.15	0.35	-0.54	0.84	0.667
Overweight	0.00	0.24	-0.47	0.47	1.000	0.25	0.32	-0.39	0.89	0.442	-0.75	0.33	-1.41	-0.09	0.025
Obese Class I	-0.70	0.25	-1.19	-0.22	0.005	-1.00	0.38	-1.75	-0.25	0.010	-0.55	0.31	-1.16	0.06	0.076
Obese Class II	0.00	0.31	-0.61	0.61	1.000	0.75	0.42	-0.09	1.59	0.079	-0.75	0.42	-1.57	0.07	0.073
Obese Class III	0.20	0.31	-0.41	0.81	0.521	0.75	0.46	-0.16	1.66	0.106	-0.99	0.40	-1.77	-0.21	0.013
Age (46+)	-0.20	0.18	-0.56	0.16	0.269	-0.25	0.27	-0.79	0.29	0.361	0.00	0.23	-0.45	0.45	1.000
Gender (Female)	0.70	0.17	0.36	1.04	0.000										
Depression	0.15	0.28	-0.40	0.70	0.594	0.25	0.52	-0.78	1.28	0.632	0.10	0.32	-0.53	0.73	0.754
Local-Global Difference															
Intercept	133.00	87.84	-39.86	305.86	0.131	102.97	102.46	-99.70	305.64	0.317	269.11	126.22	19.87	518.35	0.035
Underweight	279.67	139.76	4.65	554.69	0.046	151.50	200.31	-244.71	547.71	0.451	460.54	203.36	58.97	862.11	0.025
Overweight	-72.52	123.79	-316.12	171.08	0.558	11.51	158.19	-301.39	324.41	0.942	-198.12	197.84	-588.78	192.54	0.318
Obese Class I	-59.15	125.89	-306.87	188.57	0.639	25.46	185.79	-342.03	392.95	0.891	-136.51	180.46	-492.85	219.83	0.450
Obese Class II	-44.31	154.75	-348.83	260.21	0.775	29.25	200.31	-366.96	425.46	0.884	-137.06	242.57	-616.04	341.92	0.573
Obese Class III	501.10	158.55	189.09	813.11	0.002	96.85	224.97	-348.13	541.83	0.668	840.69	231.19	384.18	1297.20	0.000
Age (46+)	11.11	91.94	-169.80	192.02	0.904	110.79	131.40	-149.11	370.69	0.401	-17.78	134.96	-284.28	248.72	0.895
Gender (Female)	58.75	86.92	-112.29	229.79	0.500										
Depression	87.57	145.13	-198.02	373.16	0.547	800.74	253.74	298.86	1302.62	0.002	33.89	189.78	-340.86	408.64	0.858
Stroop Difference															
Intercept	316.13	79.10	160.48	471.78	0.000	282.79	95.83	93.24	472.34	0.004	109.85	101.29	-90.14	309.84	0.280
Underweight	212.64	125.79	-34.90	460.18	0.092	430.45	187.35	59.88	801.02	0.023	323.14	163.36	0.58	645.70	0.050
Overweight	-53.06	110.62	-270.73	164.61	0.632	117.11	147.95	-175.54	409.76	0.430	-51.00	156.24	-359.50	257.50	0.745
Obese Class I	37.34	113.25	-185.51	260.19	0.742	75.16	173.77	-268.55	418.87	0.666	43.30	144.78	-242.58	329.18	0.765
Obese Class II	42.57	139.34	-231.62	316.76	0.760	-70.16	187.35	-440.73	300.41	0.709	44.63	195.06	-340.52	429.78	0.819
Obese Class III	680.19	144.75	395.36	965.02	0.000	271.70	210.41	-144.49	687.89	0.199	682.25	190.17	306.75	1057.75	0.000

Age (46+)	-28.17	82.69	-190.88	134.54	0.734	8.31	122.89	-234.77	251.39	0.946	-20.01	108.10	-233.46	193.44	0.853
Gender (Female)	-196.06	78.30	-350.14	-41.98	0.013										
Depression	53.74	129.01	-200.12	307.60	0.677	-202.49	237.32	-671.90	266.92	0.395	61.90	149.90	-234.08	357.88	0.680
Keep-Track															
Intercept	10.00	0.57	8.87	11.13	0.000	11.00	0.79	9.45	12.55	0.000	9.00	0.82	7.38	10.63	0.000
Underweight	-1.00	0.91	-2.80	0.80	0.275	-2.00	1.54	-5.04	1.04	0.195	-1.00	1.33	-3.62	1.62	0.452
Overweight	2.00	0.80	0.42	3.58	0.013	1.00	1.21	-1.40	3.40	0.411	2.00	1.27	-0.51	4.51	0.117
Obese Class I	1.00	0.82	-0.62	2.62	0.225	-1.00	1.42	-3.82	1.82	0.484	2.00	1.18	-0.32	4.32	0.091
Obese Class II	1.00	1.01	-0.99	2.99	0.324	-2.00	1.54	-5.04	1.04	0.195	2.00	1.59	-1.13	5.13	0.209
Obese Class III	-3.00	1.04	-5.04	-0.96	0.004	-4.00	1.72	-7.41	-0.59	0.022	1.00	1.51	-1.99	3.99	0.509
Age (46+)	-2.00	0.60	-3.18	-0.82	0.001	-2.00	1.01	-3.99	-0.01	0.049	-2.00	0.88	-3.73	-0.27	0.024
Gender (Female)	0.00	0.57	-1.12	1.12	1.000										
Depression	0.00	0.94	-1.84	1.84	1.000	-3.00	1.94	-6.85	0.85	0.125	0.00	1.22	-2.40	2.40	1.000

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Table 10 - Adjusted quantile regressions of the upper quartile for the four cognitive measures

	Total n=315					Males only n=142					Females only n=173				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	8.25	0.07	8.12	8.38	0.000	8.25	0.08	8.08	8.42	0.000	8.15	0.06	8.04	8.26	0.000
Underweight	-0.10	0.11	-0.31	0.11	0.353	-0.10	0.17	-0.43	0.23	0.546	0.10	0.09	-0.08	0.28	0.265
Overweight	0.00	0.09	-0.19	0.19	1.000	0.00	0.13	-0.26	0.26	1.000	0.10	0.09	-0.07	0.27	0.244
Obese Class I	-0.10	0.10	-0.29	0.09	0.302	0.00	0.15	-0.30	0.30	1.000	0.00	0.08	-0.16	0.16	1.000
Obese Class II	0.00	0.12	-0.24	0.24	1.000	0.00	0.17	-0.34	0.34	1.000	0.14	0.11	-0.07	0.35	0.191
Obese Class III	-0.10	0.12	-0.34	0.14	0.413	-0.13	0.19	-0.50	0.24	0.484	0.10	0.10	-0.10	0.30	0.327
Age (46+)	-0.10	0.07	-0.24	0.04	0.160	-0.25	0.11	-0.47	-0.03	0.024	0.00	0.06	-0.12	0.12	1.000
Gender (Female)	0.10	0.07	-0.03	0.23	0.137										
Depression	0.49	0.11	0.27	0.71	0.000	0.13	0.21	-0.28	0.54	0.535	0.59	0.08	0.43	0.75	0.000
Local-Global Difference															
Intercept	423.06	145.30	137.13	708.99	0.004	353.93	154.06	49.20	658.66	0.023	752.64	147.50	461.39	1043.89	0.000
Underweight	511.08	231.18	56.17	965.99	0.028	251.84	301.19	-343.90	847.58	0.405	790.78	237.64	321.53	1260.03	0.001
Overweight	95.98	204.77	-306.96	498.92	0.640	356.03	237.85	-114.44	826.50	0.137	-101.04	231.18	-557.54	355.46	0.663
Obese Class I	105.84	208.23	-303.91	515.59	0.612	350.81	279.36	-201.75	903.37	0.211	-154.92	210.87	-571.31	261.47	0.464
Obese Class II	-3.96	255.97	-507.66	499.74	0.988	302.36	301.19	-293.38	898.10	0.317	-178.13	283.45	-737.83	381.57	0.531
Obese Class III	785.40	262.26	269.31	1301.49	0.003	774.57	338.26	105.50	1443.64	0.024	1130.69	270.15	597.24	1664.14	0.000
Age (46+)	157.83	152.07	-141.42	457.08	0.300	226.96	197.57	-163.82	617.74	0.253	31.98	157.71	-279.44	343.40	0.840
Gender (Female)	132.56	143.77	-150.36	415.48	0.357										
Depression	245.87	240.06	-226.52	718.26	0.307	268.89	381.52	-485.74	1023.52	0.482	-339.50	221.76	-777.40	98.40	0.128
Stroop Difference															
Intercept	632.52	133.95	368.93	896.11	0.000	667.89	151.42	368.39	967.39	0.000	438.26	190.31	62.49	814.03	0.023
Underweight	292.34	213.03	-126.86	711.54	0.171	232.38	296.02	-353.14	817.90	0.434	316.90	306.94	-289.16	922.96	0.303
Overweight	-141.16	187.32	-509.77	227.45	0.452	-40.62	233.77	-503.01	421.77	0.862	-215.81	293.56	-795.46	363.84	0.463
Obese Class I	22.26	191.78	-355.13	399.65	0.908	-66.71	274.56	-609.79	476.37	0.808	103.21	272.04	-433.94	640.36	0.705

Obese Class II	201.87	235.96	-262.46	666.20	0.393	-133.19	296.02	-718.71	452.33	0.653	559.31	366.50	-164.36	1282.98	0.129
Obese Class III	1161.47	245.12	679.11	1643.83	0.000	1306.45	332.46	648.86	1964.04	0.000	1161.47	357.32	455.93	1867.01	0.001
Age (46+)	221.50	140.02	-54.04	497.04	0.115	521.19	194.18	137.12	905.26	0.008	174.95	203.12	-226.11	576.01	0.390
Gender (Female)	-194.26	132.60	-455.19	66.67	0.144										
Depression	-100.78	218.47	-530.69	329.13	0.645	-236.69	374.97	-978.37	504.99	0.529	-101.70	281.65	-657.83	454.43	0.719
Keep-Track															
Intercept	13.00	0.58	11.86	14.14	0.000	13.00	1.06	10.91	15.09	0.000	13.00	0.66	11.69	14.31	0.000
Underweight	-1.00	0.92	-2.82	0.82	0.279	-1.00	2.07	-5.09	3.09	0.629	-1.00	1.07	-3.12	1.12	0.352
Overweight	1.00	0.81	-0.60	2.60	0.219	1.00	1.63	-2.23	4.23	0.541	1.00	1.03	-1.03	3.03	0.331
Obese Class I	0.00	0.83	-1.63	1.63	1.000	0.00	1.92	-3.79	3.79	1.000	1.00	0.95	-0.88	2.88	0.294
Obese Class II	-1.00	1.02	-3.01	1.01	0.328	-1.00	2.07	-5.09	3.09	0.629	0.00	1.28	-2.53	2.53	1.000
Obese Class III	0.00	1.05	-2.06	2.06	1.000	-2.00	2.32	-6.59	2.59	0.390	1.00	1.22	-1.41	3.41	0.414
Age (46+)	-1.00	0.61	-2.19	0.19	0.100	-1.00	1.36	-3.68	1.68	0.462	-2.00	0.71	-3.40	-0.60	0.005
Gender (Female)	0.00	0.57	-1.13	1.13	1.000										
Depression	-1.00	0.95	-2.86	0.86	0.291	-1.00	2.62	-6.18	4.18	0.703	-2.00	0.98	-3.94	-0.06	0.044

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Table 11 - Non-parametric correlations (Kendall tau-b) between BMI and the four cognitive tests

	Correlation	p-value
Cognitive tests:		
Random Number Generation	-.087	.061
Local-Global Task	-.021	.620
Stroop Task	.018	.655
Keep-Track Task	.040	.348

Kendall's tau-b correlations were run to determine the relationship between BMI and the four cognitive tests. None of the pairings were statistically significant. Correlation results can be found in Table 11.

4.10.5. Waist Circumference

Table 12 reports the means, standard deviations and p values for the waist circumference risk groups. For the random number generation task there were homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .546$). A one-way ANOVA found that there were no statistical differences between the waist circumference risk groups, $F(3, 189) = 1.387$, $p = .248$. For the Local-Global task there were homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .499$). A one-way ANOVA found that there were no statistical differences between the waist circumference risk groups, $F(3, 187) = .991$, $p = .398$. For the Stroop task there were homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .418$). A one-way ANOVA found that there were no statistical differences between the waist circumference risk groups, $F(3, 189) = 2.31$, $p = .078$. For the Keep-Track task there were homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .596$). A one-way ANOVA found that there were no statistical differences between the waist circumference risk groups, $F(3, 189) = 2.359$ $p = .073$.

Table 12 - Means and SD of the cognitive tasks by waist circumference risk together with p-value from a one-way ANOVA

	No Increased Risk	Increased Risk	High Risk	Very High Risk	p-value
N	145	11	9	28	
Random Number Generation[1]	7.51 (.95)	7.55 (.915)	7.03 (.964)	7.21 (1.04)	.248
Local-Global Task[2]	347.66 (701.51)	159.35 (796.87)	-13.25 (437.23)	274.55 (667.81)	.398
Stroop Task[3]	414.33 (697.40)	193.74 (718.93)	833.90 (947.96)	674.00 (779.58)	.078
Keep-Track Task[4]	9.51 (3.96)	12.27 (3.64)	11.33 (3.24)	9.75 (4.03)	.073

[1] A high score = better performance.
[2] Local-Global Difference = Local-Global Conflicting - Local-Global Consistent. A high score = slower performance.
[3] Stroop Task Difference = Stroop Incongruent – Stroop Congruent. A high score = slower performance.
[4] A high score = better performance.

4.11. Discussion

Study One explored the relationship between weight and executive function in a community sample, seeking to clarify at what classification level of BMI are cognitive deficits evident and which, if any, cognitive deficits are evident. Several key findings emerged from this investigation. Firstly, the relationship between weight and executive functions was consistent across the cognitive tests, the weight classifications and between the gender groups. Secondly, participants who were classified as obese class III underperformed on tests of inhibition, updating and shifting. Finally, an underweight classification impacted performance on tests of inhibition, shifting and updating. These findings took into the account potential confounding factors such as depression, age and clinical factors.

On inhibition (Stroop task) performance, results showed that underweight and obese class III individuals responded considerably slower when identifying the colour of the word on incongruent trials. This suggested that adult obese participants responded more impulsively on an interference control task. These data are similar to those obtained by others, where obese and underweight samples showed impaired performance on this test of inhibition. Catoira et al. (2016) utilising the Stroop task also found a deficiency in inhibition in obese women versus a healthy weight control group. Fagundo et al. (2012) also found that an all-female obese group showed deficits during the performance of the Stroop test. These results add to the literature that inhibition is hindered by an increased BMI, a process thought to be critical for suppression of inappropriate/unwanted actions that can interfere with achieving cognitive, motor, or emotional goals. This inability to inhibit inappropriate thoughts could also relate to maladaptive eating behaviours and the difficulty that those with impairments may have in making appropriate food choices. In the obese this could lead to overeating and binge eating whilst for the underweight this could lead to reduced eating or compensatory behaviour such as vomiting or excessive exercise Perpiñá et al. (2017).

When the groups were compared on a set-shifting task (Local-Global task), two group's underperformed: the class III obese and underweight groups. These groups were slower when responding to conflicting stimuli, where individuals had to move from one rule to another with a bigger time difference between the conflicting and consistent blocks. Poor cognitive flexibility is a consistent finding across an underweight population, more so for those with anorexia nervosa (Perpiñá et al., 2017; Tchanturia et al., 2011). Gameiro et al. (2017) reported the existence of differences in set-shifting between their obese and normal weight groups, revealing that obese individuals have more difficulty in switching and changing between tasks and rules. Galioto et al. (2013) also confirmed that a higher BMI was associated with poorer performance on tests of shifting, finding that their individuals have difficulty changing between sets and tasks. Alongside the current study this highlights that an elevated BMI can act as an obstacle and may hinder the ability to switch between tasks flexibly as well as the potential to affect the mental ability one would need to learn and change a behaviour when a rule changes.

On updating (Keep-Track task) performance, underweight individuals and those in the upper obese class III group performed worse compared with the other classifications. They recalled fewer words on a memory task suggesting that it was difficult for these weight groups to update their working memory and provide correct answers. These results for the obese classes were reflected in Stingl et al. (2012) findings, they observed that a normal weight group correctly responded significantly more than the obese group, concluding that increased body weight is associated with reduced task performance. Cohen et al. (2011) also supported the evidence that a normal weight group outperformed an obese group on a working memory / updating task. This is also reflected in underweight research where performance on working memory tasks has been associated with low body weight independent of known covariates (Narimani et al., 2019). The outcome of these results suggests that those on the extreme ends of the weight scale may be at a disadvantage and have difficulties when recalling information from working memory.

Study One draws the conclusion that extreme weight conditions are associated with deficits in executive functions, that a classification as underweight or obese class III can be detrimental to the executive functions, updating, shifting and inhibition. That those who are a normal weight, overweight and in the lower obese classes have an advantage over both underweight and obese class III individuals. Past research reflected in the earlier systematic review (Chapter 3 p. 56) have mainly evaluated comparisons between normal weight and obese individuals and the results found no other studies which had evaluated the full scope of the BMI scale. This study represents a significant contribution to the research literature as it has introduced the full range of BMI classifications in line with

WHO guidelines and has been able to pinpoint at which stage of obesity individuals within this sample may be at a disadvantage.

This study has also reinforced the thought that an elevated BMI level can impact executive function with a similar pattern across all three executive function domains: inhibition, updating and shifting. In the current study, common across all three executive functions were the deficits shown by those in the obese class III with the addition of the obese class II seen to hinder the completion of a test of updating. The association between obesity and executive function has consistently been found in several studies (Cohen et al., 2011; Fagundo et al., 2012, Galioto et al., 2013; Restivo et al., 2017). They have found that obese individuals compared to normal weight individuals are outperformed during multiple tests of executive functions using cognitive behavioural tests. This is reiterated by one of the main research groups led by Gunstad (2007) who when examining executive function in healthy individuals across the adult life span found that reduced executive function performance across all the domains differed between normal weight and obese adults when adjusting for possible confounds.

On cognitive tests of inhibition, shifting and updating, underweight individuals were also seen to be at a disadvantage. There has been past research which has highlighted that an underweight BMI classification has had a negative effect of executive function skill, with those with anorexia nervosa displaying a similar profile of executive dysfunction as obese individuals with both long-term obesity and long-term underweight being associated with lower cognitive performance in late midlife (Sabia et al., 2009; Fagundo et al. 2012). Furthermore, mirroring obesity there is some evidence that underweight individuals in midlife are more likely to develop dementia later in life (Qizilbash et al, 2015). The current results suggest that being underweight is a risk factor for poorer executive function performance.

Interestingly, across the cognitive tests the female only data highlighted more differences compared to the male only data across the updating, inhibition and complex tasks. It was suggested by Gameiro et al. (2017) that gender balancing and the inclusion of both genders was as an area of importance and this has been embraced here. Gameiro and colleagues, suggested that females were at a disadvantage compared to males on tests of shifting and cognitive flexibility. In the current work, across the cognitive tests, poorer performance was more often displayed by the female group. Previous work on gender differences across executive functions has not been consistent. Gaillard et al. (2021) found that overall, there were no significant sex differences across the executive function domains when accounting for forty-six study results. Within the current study, females classified as underweight or obese perform worse than males on tests of shifting and inhibition. In contrast to this, studies inclusive of females have been known to hypothesise that females have an advantage over males on tasks of inhibition. This is due to the influence of oestrogen which is a known factor in helping to facilitate dopaminergic transmission which is linked to the ability to inhibit (Gaillard et al., 2021). There is the potential that there is an underlying biological impairment in the extreme weight groups which would hinder executive function performance. The inconsistency in results shows the importance of exploring the differences in gender ability not just for executive functions but across the cognitive spectrum.

Much of the previous work researching the association between an underweight classification and executive function has focused solely on underweight being defined by an eating disorder. This is very different to how the current study has collected data which has used an opportunity sample methodology. Within Study One, an underweight classification does not define an individual as having clinical anorexia nervosa or bulimia nervosa. Comparatively it has been difficult to find research which has evaluation of underweight individuals and executive function without a clinical cause. This study is a contribution to this research area which is lacking in a community sample of underweight individuals.

Interestingly this study has highlighted performance disadvantages at either ends of the BMI scale. Underweight and obese individuals may potentially share some mechanisms and lifestyle similarities which would account for these results. Malnutrition is often associated with underweight individuals and the deficiencies in their intake of nutrients and energy. This also refers to the excesses and imbalances of these nutrients and energy which exist in obese populations. The WHO states that worldwide, there are almost 1.9 billion people who are overweight or obese and 462 million people who are underweight, who would be classified as being malnourished (WHO, 2020).

De Lorenzo et al. (2020) concluded that a marker of poor nutrition is obesity, highlighting that over 80,000 new cases of cancer in adults in 2015 were associated with suboptimal nutrition and obesity (Zhang et al, 2019). Poor nutrition is represented by the foods which are common to the Western diet. They are highly processed, calorie dense and are poor in micronutrients and antioxidants. It has been found that nutrition is an important lifestyle factor and it affects cognitive impairment and the risk of dementia (Scarmeas et al., 2018). Studies have suggested a number of additional nutrients in diets can alleviate against cognitive decline and risk of dementia (Barberger-Gateau, 2014). For example, the Mediterranean diet has been associated with preventing memory loss and dementia (Scarmeas et al., 2006; Lourida et al., 2013; Petersson et al., 2016). Ballarini et al. (2021) revealed improved memory performance on cognitive tasks for those following a Mediterranean diet. This diet also potentially plays a part in interfering with the build-up of two proteins which are believed to contribute to medial temporal region changes in the brain involved in memory and linked to Alzheimer’s disease. Poor nutrition may provide a reason for the similarities within the upper and lower BMI classes. The reasons for the malnutrition may be different across the groups but they are still lacking in the nutrients which could be crucial to cognition and ultimately cognitive performance.

There is the potential that the obese and underweight groups are hindered cognitively due to the resources which are available for them to complete the tasks. Resource theory (Kahneman, 1973; Norman & Bobrow, 1975; Wickens, 1983) suggests that the capacity to process information is naturally reduced because general cognitive mechanisms, such as flexibility and allocation, share common resources. According to this theory tasks of executive functions will load these mechanisms to capacity and performance will be affected by this. For the overweight and obese groups this may be where the deficit lies, in that the ability to allocate resources efficiently could impact task performance more readily than the other groups.

Waist circumference measurements were also considered but no significant differences were found on any of the cognitive tests. There was support from the advisory body NICE (2014), to acknowledge waist circumference alongside BMI to present a better indication of total body fat. In this study, the waist circumference measurement, categorised by levels of risk, seems to not impact performance compared to the categorisation of individuals by BMI. The use of a weight circumference measurement is meant to provide a better picture of the impact of excessive weight by accounting for central abdominal obesity whereas the BMI measurement does not fully allow for this and is seen to represent a practical estimate of obesity (Lean et al., 1995). It is possible that both of these indicators are measuring a different element of weight and obesity.

Additionally, this study adds to the much-needed community sample work which is required to understand executive function in a non-clinical setting. Much early work was based upon recruitment from clinical samples with a focus on the clinical and the obese. Of those studies which had established a community population it was commonly concluded that there were no differences between normal weight and obese groups (Ariza et al., 2012; Bongers et al., 2015; Catoira et al., 2016; Navas et al., 2016; Nederkoorn et al., 2006). For those research groups who have found a significant difference in cognitive performance between the weight groups the sole reason has not always been BMI classification itself but has been due to other key factors. Stanek et al.'s (2013) findings indicated that an elevated BMI was associated with decreased executive function performance. However, BMI was not independently related to executive dysfunction and an interaction with age suggested that obesity-related executive deficits increased with age. This current study has accounted for these potential differences and found that there are differences between the weight groups independent of other potentially factors including age.

Study One has established an relationship between weight and executive function across the three specific executive functions. However, this study has not been able to reinforce the theory that there is potential overlap of the executive functions supportive of Miyake et al (2000) theory. The idea that executive functions are not entirely independent from each other would lead us to believe that if deficits were found in the individual executive functions then there would also be deficits found when completing a complex task. Interestingly our complex task, Random Number Generator, does not follow this pattern. Thought to require a number of high-level executive functions processes including updating, inhibition and switching this task resulted in no differences between the weight groups. With this result in mind and with the majority of research utilising behavioural cognitive tests to measure, we must begin to question the tests themselves. What are the cognitive tasks tapping into? What does underperformance on a task actually mean? Despite the knowledge from cognitive tests batteries, it is still unclear what and how a deficit in the executive functions impact our everyday life.

4.11.1. Implications

As this study is unique in its consideration of all six classifications of BMI, there are implications for both clinicians and academics. This study has highlighted the impact that specific weight groups can have on executive function ability and that these can differ within the three obesity class groups. This demonstrates a need to consider the association between executive function and weight which is not just restricted to the comparison of a normal weight group with a single obese group but also examines a whole range of classifications and other weight measurements. Furthermore, a consideration has to be made about the executive function ability of underweight groups, a focus has often been on either those with an eating disorder or individuals who are obese. Research to provide an overall picture of weight performance on tasks would be welcomed with a view to determine whether there are similar or different reasons for the deficits in these two weight groups.

This study like many others has solely recognised differences in executive functions based upon the use of behavioural cognitive tests but it would be advantageous to consider for future research methodology evaluating how deficits in executive function may alter an individuals everyday life, a real world perspective.

4.11.2. Limitations

This study is not without its limitations. For the Stroop task and Local-Global task which both used response times as a measure, it would also have been useful to have recorded details on the accuracy of the answers. The study data provides detail of the speed at which a participant responded to the stimuli but not if their answers were correct. This has meant that this study may not been able to provide true evidence of impaired performance which may have been able to provide more clarity on how the weight and executive function are associated.

The small number of stimuli for each task could also pose a problem. As this study has been carried out on a community sample with a limited timeframe it has meant that the cognitive tests have been shortened. Consequently, the tasks have fewer trials and blocks compared to other versions. In a task such as the local-global task where the ability to successfully switch from one task to another is the main outcome, there were limited switches between congruent and incongruent trials. A measure of executive function is still being collected but the outcome variable is limited. The larger the number of stimuli for each task the more the executive functions are being tapped into. The high-level cognitive processes which are captured between trials such as the incongruent and congruent are more and therefore this will provide a better representation of task performance. There is the potential that the data collected for this study will only provide a basic understanding of executive function performance. It would have been beneficial to have the additional blocks and tasks to strengthen the analysis and provide a more robust picture within this population. However, the population itself and the circumstances in which the testing took place were the main factors for this restriction. The length of the study was a condition of being able to recruit to a community population, this was especially true of the business sample. The solution was to compromise and shorten the tests to allow the testing of executive function within these populations. A key strength of this study is the large participant numbers and it would not have been achievable with a longer test battery.

There are certain extra self-report measures, which in hindsight would have been useful to collect and provide a full self-report health background. A drawback to using a sample in a community setting is the lack of availability of a full clinical background of the participants. This may have provided an understanding of all the BMI group, in relation to past and current eating behaviours and problems. This would have been especially useful in the underweight and obese groups where the knowledge of an eating disorder behaviour such an anorexia nervosa or bulimia nervosa or a medical intervention such as bariatric surgery would have been an additional variable to consider.

This study has relied on a single test to measure each of the executive functions: updating, inhibition and shifting. This study was time sensitive as this was carried out outside of the laboratory and in community settings such as community centres and workplaces. With time restraints in place it was crucial that when designing the cognitive test battery that only the minimum number was used with the fewest number of blocks needed to provide robust data. However, it would have been useful to have used multiple cognitive tasks to test for each executive function. The ability to be able to corroborate each task results with a similar testing task would have further strengthened the study and its results.

4.12. Conclusions

Overall, Study One has provided an insight into the relationship between weight and executive function by demonstrating a difference between the weight groups on behavioural cognitive tests among a community sample. These associations highlight the cognitive advantage that normal weight and overweight individuals hold over those who are obese, specifically obese class III, and underweight. It was also established that there were some differences between the genders with the female sample performing worse compared to the male sample. To understand these advantages in full there is a future need for research to establish the relationship between the results acquired from behavioural cognitive tests and the data acquired from self-report methodologies. If the executive function tasks can account for cognitive deficits, there is a need to understand how that translates in the real world and how this effects an individual which may be demonstrated through standardised self-report questionnaires.

Chapter 5. Study Two

5.1. Introduction

5.1.1. Performance-Based Measurements

A standard measurement of executive function is a performance-based task measuring a set behaviour. These cognitive tests are usually administered in a laboratory environment which provides standardised conditions. An advantage of using these tasks is that everything can be controlled resulting in each participant and patient being presented with the same stimuli in the same way. This methodology is commonplace in executive function literature and with a number of cognitive behaviour tests being utilised to measure performance. Deficits in executive function in an obese population using performance based behavioural measures have been shown in the systematic review and Study One (Chapter 3 & Chapter 4).

Performance-based tasks include the Stroop Task (Stroop, 1935), a test of inhibition to demonstrate the ability to control dominant responses. The commonly used Wisconsin Card Sorting Task (Heaton, Chelune, Talley, Kay, and Curtis, 1993) requires an individual to learn what the rule of the task is and change tact appropriately in order to gain correct responses and complete it successfully. The Trail Making Test (Reitan,1992) requires an individual to complete a task as quickly as possible whilst still maintaining accuracy and testing cognitive flexibility. There are a wide range of performance tasks which are linked to the executive functions and it is unsurprising that they are still a go-to for contemporary research. However, the performance-based measures inclusive of reaction times and accuracy may not provide clarity in a clinical setting. A practical overview needs to be provided and this often comes in the form of self-rating methodologies.

5.1.2. Self-Reported Measurements

It was suggested by Burgess (1997) that neuropsychological tests alone were not enough to assess executive function due to the attempts to split the integrated functions into standalone domains. That these performance-based whilst measuring individual components could not provide a realistic overview of the demands of the real-world. Roth, Isquith and Gioia (2005) saw a need for complementary testing which was ecologically valid and could account for and capture complex, every day, problem-solving demands. They argue that the importance of gathering such data allows predictions to be made about how an adult can function in their everyday environment. Using this allows practical recommendations to be made by professionals and from this the implementation of person specific interventions can be put in place. They further believe that an individual's everyday environment can be an important setting to observe the executive functions "in action". From this thinking came The Behaviour Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, and Kenworthy, 2000), the development of a rating scale for parents and teachers to understand executive functions in adolescents, school-aged children and pre-schoolers. With the success of this tool and it having demonstrated reliability and validity the Adult version, The Behaviour Rating Inventory of Executive Function – Adult Version (BRIEF-A: Roth, Isquith Gioia,2005) was developed to capture an adults views of the strengths and weaknesses of their own executive functions. This self-rating method accounts for the information that an individual has about their own daily activities that may provide an understanding about their executive function capability.

The BRIEF-A considers nine nonoverlapping clinical scales which measure different aspects of executive function which include 'Inhibit', 'Shift', 'Emotional Control' and 'Working Memory'. The self-report itself is a two page form which consists of 75 items, each of which are linked to one of the nine clinical scales and are related daily activities with the same question being considered for each "During the past month, how often has each of the following behaviours been a problem?" Items include making reference to organisation, forgetfulness, planning, emotional mood and problem solving. The BRIEF versions have become the most commonly used rating scale of executive function in recent years but other useful scales include Executive Function Index (Miley and Spinella, 2006; Spinella, 2005) and Brown Attention-Deficit Disorder Scales for adolescent and adults (Brown, 2001).

The systematic review highlighted that a limited number of studies have used both self-rating and performance-based measures to test for executive function with the focus of findings being based upon cognitive test performance. This has meant studies have not been able to provide an overview of how an individual may be affected by potential deficits which the cognitive tests have highlighted. More importantly these studies have not been able to provide an overview of how they may be affected in their everyday lives i.e. how does poor performance on a test of inhibition translate in the real word. From a methodological standpoint it would also be useful to try to establish if there is a relationship between the executive functions that the performance-based and self-rating measure i.e. is set-shifting performance on the Local-Global task relative to the shift rating on the BRIEF-A (Toplak et al., 2013).

If performance and rating measures of executive function are assessing the same general construct, then it would be believed that they should be positively correlated. Toplak, West and Stanovich (2013) assessed where performance-based tests and rating tests measured the same executive function construct. Reviewing twenty studies of which thirteen had used the BRIEF-A rating scale, only one of which had an only adult population and one was a non-clinical study. Of the 182 correlations only 35 (19%) were statistically significant leading to the conclusion that there was a weak association between the ratings on the BRIEF-A and the performance-based measure of executive function. This lack of association was thought to be due to the ratings and performance tests tapping into difference levels of executive function. The executive functions have broad definition but are measured narrowly. Salthouse et al. (2003) goes on to explain this difference in that the structure of a performance task is mostly experimenter led and does not require a participant to be involved. This is further supported by Gioia et al (2008), that optimal performance is determined by the researcher with very little participant input. Whereas on tests where ratings have been utilised, this allows full engagement from the participant about their executive function ability. Performance based measures of executive function were concluded to provide rich information about processing whereas ratings provide a deeper look at goal pursuit (Toplak, 2013). This work highlights that it cannot be assumed that performance and rating measures capture executive function in the same way, especially in a children and adolescent population as well as in clinical settings but little is still known in an adult and non-clinical population.

5.1.3. Loneliness and Sleep Quality

Work has shown links between depression and obesity (Milaneschi et al., 2019; Luppino et al., 2010; Faith et al., 2011) but further to this there have been other associations, loneliness and sleep quality, often linked with depression which has stemmed into additional pools of obesity work. Loneliness is the negative feeling that occurs when a person does not perceive their social relationships to be as satisfying as they would like (Perlman & Peplau, 1981). Research has shown positive associations between obesity and loneliness, with Day et al. (2018) showing positive causal effect of BMI on loneliness but not for loneliness on BMI. The Jung and Sikorski (2019) study aimed to investigate the link between loneliness and obesity using the 3-item version of the UCLA loneliness Scale (Hughes et al., 2004) and found no significant relationship. The relationship remains unclear and warrants further investigation.

Studies have also showed a relationship between poor sleep quality and obesity. Resta et al. (2003) compared obese subjects to normal weight controls and found the obese group to have significantly higher sleep latency and lower sleep efficiency. Chaput et al. (2005) investigated improvements in sleep quality in men losing weight with a lower baseline BMI and saw a significant improvement in sleep quality with a 5% weight loss. Instruments such as the The Pittsburgh Sleep Quality Index (PSQI) (Buysee, 1988) aim to provide a reliable, valid and standardised measure of sleep quality, to distinguish between good and poor sleepers. The addition of the loneliness and sleep quality variables might explain significant variances between the weight groups and provide a better understanding of the complexities of relationship between weight and cognitive function.

5.2. Aims

Study Two looks to address the use of different methodologies to evaluate executive functions across a range of weights (BMIs) in a community population. The study looks to evaluate the relationship between weight and executive function using both performance-based and self-report methodologies.

The previous experimental Study One (Chapter 4) provided an insight into behaviour-based task performance in a community setting, specifically highlighting cognitive disadvantages in those that are classified as obese class III and underweight on the BMI scale. A community population will also be recruited to the current study and it is expected that these results will be replicated to further establish these findings. The aims of this study are:

(a) to identify the association between weight and executive function using four performance-based tasks and a self-report measure in a community sample.

(b) to see if there are any associations between executive function performance-based tasks and an executive function self-report measure. To understand if performance on cognitive tasks can be linked to self-reported daily difficulties.

(c) to assess whether loneliness and sleep quality are associated with weight in a community setting.

5.3. Methods

5.3.1. Ethics

The University of Central Lancashire PsySoc Committee granted full ethical approval for this project (ref. PSYSOC 199). All personal data used within the study was maintained in accordance with the data protection act 1998. Upon recruitment, all participants were given a unique identification (ID) number which was used on all future paper and computer records. There was one document linking the names to the ID numbers which was kept under lock and key in the Darwin Building on the University of Central Lancashire (UCLan) campus.

All computer records were password protected and made anonymous, whilst paper records were stored in a separate locked filing cabinet on UCLan campus. Upon study completion, all personal data including paper and computer records will be kept in a locked filing cabinet on UCLan campus for 5 years.

5.4. Participants

Participants (n= 400) were recruited for this study over an 18 month period. Participants were aged between 18-65 years (mean = 37.32 years) and 53.6% were female. Demographic characteristics of participants is shown in Table 13.

Table 13 - Demographic characteristics of participants in Study Two

		n	%
Recruitment	Business	153	38.3
	Community	165	41.3
	Student	82	20.5
Gender	Male	185	46.3
Relationship	Single	199	49.8
	Married	168	42.0
	Divorced	33	8.3
Age (years)	18-25	122	28.0
	26-35	92	23.0
	36-45	67	16.8
	46-55	74	18.5
	56-65	55	13.8
Employment	Employed	278	69.5
	Unemployed	51	12.8
	Student	70	17.5

5.4.1. Selection of Participants

The recruitment of participants was from three main community populations: business population, community population and university (staff and student) population. Participants were invited to participate in the study if they were of working age (18 years – 65 years). Participants were English literate with the ability to utilise computer-based equipment.

5.4.2. Recruitment

The same recruitment strategy adopted in Study 1 was continued in Study 2. A number of businesses maintained their support and allowed the continued recruitment of staff members for Study 2. Additional businesses from the business tower interested in participating were included in this study. The same community centre groups were approached to participate alongside additional groups which had been added to the community centre calendar since the end of Study 1 recruitment. If an individual had participated in Study 1, they could not participate in Study 2.

5.5. Self-Report Materials

5.5.1. Demographic information and Clinical variables

The same demographic information and clinical variables were collected via the questionnaire used in Study 1. The demographic information collected included age, gender, employment and postcode and the clinical variables collected included diabetes, heart disease, asthma/lung disease, stroke, high blood pressure and high cholesterol.

5.5.2. Patient Health Questionnaire -8 (PHQ-8; Spitzer, Kroenke & Williams, 1999)

The Patient Health Questionnaire-8 (PHQ-8) was used as a depression screener. The scale is predominantly used in clinical setting as a multipurpose tool for screening, diagnosing, monitoring and measuring depression (shown in Appendix 8). It incorporates Diagnostic and Statistical Manual of Mental Disorder, Fourth Edition (DSM-IV) depression diagnostics criteria with other depressive symptoms. This scale is one of the most validated tools in mental health, it is advocated by the National Institute for Health and Care Excellence and is operated by many guidelines of mental health screening in chronic conditions. The PHQ-8 was therefore used as an alternative to the CES-D which was utilised in Study One. Participants were instructed to complete the PHQ-8 form by indicating how often they had been bothered by each problem in the last 2 weeks (‘Feeling down, depressed, or hopeless’ ‘Feeling tired or having little energy’.) The score is calculated by assigning scores of 0, 1, 2, and 3, to the response categories of ‘not at all’, ’several days’, ‘more than half the days’ and ‘nearly every day’ respectively. The score for each item are summed to produce a total score between 0 and 24. A total score of 0-4 represents not significant depressive symptoms. A total score of 5 to 9 represents mild depressive symptoms; 10 to 14, moderate; 15 to 19, moderately severe; and 20 to 24, severe. A PHQ-8 score above 10 which has a 88% sensitivity and 88% specificity for major depression typically represents clinically significant depression and would lead to a clinical referral (Kroenke et al., 2001). This is the cut-off that this study will adopt. The scale has been validated by the developers and it was found to demonstrate good internal consistency (α=.89) and good test-retest reliability (r=.84 -.95) (Kroenke et al., 2001).

5.5.3. The Pittsburgh Sleep Quality Index (PSQI; Buysee, 1988)

The Pittsburgh Sleep Quality Index is an effective instrument used to measure the quality and patterns of sleep, differentiating poor sleepers from good sleepers (shown in Appendix 9). Nineteen items are grouped into 7 component scores and weighted equally on a 0-3 scale. Components are a combination of qualitative and quantitative items, and include: Subjective Sleep Quality, Latency, Duration, Habitual Sleep Efficiency, Sleep Disturbances, Use of Sleep Medication and Daytime Dysfunction. Component scores are summed to provide a global score ranging from 0-21. A high score indicates poor sleep quality. A cut off score of 5 gave a sensitivity of 89.6% and specificity of 86.5%, with a group-wide kappa of 0.75 ($p < 0.001$) (Buysse et al, 1989). A score above 5 is now generally accepted as indicating poor quality sleep.

5.5.4. The Behaviour Rating Inventory of Executive Function–Adult Version (BRIEF-A; Roth, Isquith & Gioia, 2005)

The Behaviour Rating Inventory of Executive Function – Adult Version (BRIEF-A) is a standardised self-report methodology developed to capture an individual's assessment of their own executive functions (shown in Appendix 10). This is measured by reviewing everyday behaviours which are associated with specific executive function domains. The adult version is designed to be completed by participants between the ages of 18 and 90 years. The BRIEF-A is composed of 75 items within nine non-overlapping clinical scales that measure different aspects of executive functioning: Inhibit, Shift, Emotional Control, Self-Monitor, Initiate, Working Memory, Plan/Organise, Task Monitor, and Organisation of Materials. Table 14 describes the clinical scales. Items are based on a frequency scale that ranges from (N) Never, (S) Sometimes, to (O) Often. For each of the nine scales a raw numerical score was calculated. These scores were transformed into T-scores using the appropriate age-normative comparison group found in the BRIEF-A Professional Manual (Roth & Gioia, 2005). Three further scores were calculated; Behavioural Regulation Index (BRI), Metacognition Index (MI), Global Executive Composite (GEC). The BRI represents an individual's ability to regulate and/or control emotional and behavioural responses. A BRI raw score was created by summing the Inhibit, Shift, Emotional Control, and Self-Control scales. The MI represents an individual's ability to plan, problem solve and organise. A MI raw score was created by summing the Initiate, Working Memory, Plan/Organise, Task Monitor and Organisation of Material scales. The GEC is a summary measure which combines all the executive function abilities, the raw score is composed of the addition of all nine clinical scales. The raw score for each of the BRI, MI and GEC were transformed into T-scores. The BRIEF-A has demonstrated evidence of the reliability, validity, and clinical utility for ecologically valid assessment of executive functioning in individuals across the adult spectrum. For the normative sample, internal consistency was moderate to high with alpha coefficients ranging from .73 to .90 for the clinical scales. On a subset of healthy adults, the test-retest correlations across the clinical scales ranged from .82 to .93 (Roth et al., 2005).

Table 14 – The Behaviour Rating Inventory of Executive Function – Adult Version Clinical Scales and Behavioural Descriptions

Clinical Items	Behavioural Description	Number of Items
Inhibit	Control impulse, appropriately stop own behaviour at the proper time.	8
Shift	Move freely from one situation, or aspect of a problem, to another as needed; solve problems flexibly.	6
Emotional Control	Modulate emotional responses appropriately.	10
Self-Monitor	Keep-Track of the effect of own behaviour on others; attend to own behaviour in the social context.	6
Initiate	Begin a task or activity; fluidly generate ideas.	8
Working Memory	Hold information in mind for the purpose of completing a task; stay with, or stick to, an activity.	8
Plan/Organise	Anticipate future events; set goals; develop appropriate steps to carry out an associated action; carry out tasks in a systematic manner; understand main ideas.	10
Task Monitor	Check work; assess performance during or after finishing a task to ensure attainment of goal.	6
Organisation of Materials	Keep workspace, living areas, and materials in an orderly manner.	8

5.5.5. UCLA Three item Loneliness Scale (Hughes et al., 2004)

The UCLA Three Item Loneliness Scale developed by Hughes et al. (2004) is a shortened version of the UCLA Loneliness Scale (shown in Appendix 11). The number of items was reduced from 20 items to 3 items and the response format was shortened from four response categories to three response categories. It was reported that there was a high correlation between this 3-item shortened version and the full the 20-item scale. Participants were instructed to complete the loneliness scale by indicating how often they felt a certain way about different aspects of their life. The response is a three-point scale ranging from 1 to 3 indicating the frequency of feelings: ‘hardly ever,’ ‘some of the time,’ and ‘often.’ The score is the sum of the 3 questions with a higher total score indicating greater loneliness. The scale has been validated and found to demonstrate adequate internal consistency (α=.72) (Hughes et al., 2004).

5.6. Weight, Height and Waist Circumference Measurements

The same procedure established in Study 1 was used in the current study. Weight was taken using Tanita Digital Medical Scales, waist circumference was measured using a tape measure and height was obtained using a stadiometer (a device with a sliding head plate, a base plate and back plate with measuring scale).

From the measurements of weight and height, Body Mass Index (BMI) was calculated as a ratio of weight (kg) to height (m) squared. BMI was classified using the WHO BMI groups (kg/m^2; underweight BMI < 18.5; normal weight BMI 18.5 - 24.9; overweight BMI 25.0 – 29.9; class I obesity BMI 30.0 – 34.9; class II obesity BMI 35.0 – 39.9; class II obesity BMI > 40.0).

5.7. Behavioural Cognitive Tests

The tasks used in the first study were the same as the second study. Participants were invited to complete the Stroop task, Local-Global task, Keep-Track task and the Random Number Generator task. The experiment was executed using E-Prime 2.0 software (Psychology Software Tools, 2012) on a laptop computer.

5.8. Procedure

The current study followed the same procedure as Study 1. In this study there were additional self-reporting methods which were randomly assigned to be completed before or after the behavioural cognitive tests. To control for depression and sleep, the PHQ-8 and the Pittsburgh Sleep Quality Index were administered. The BRIEF-A was completed as a self-report measure of executive function. The procedure for Study 2 is shown in Figure 9.

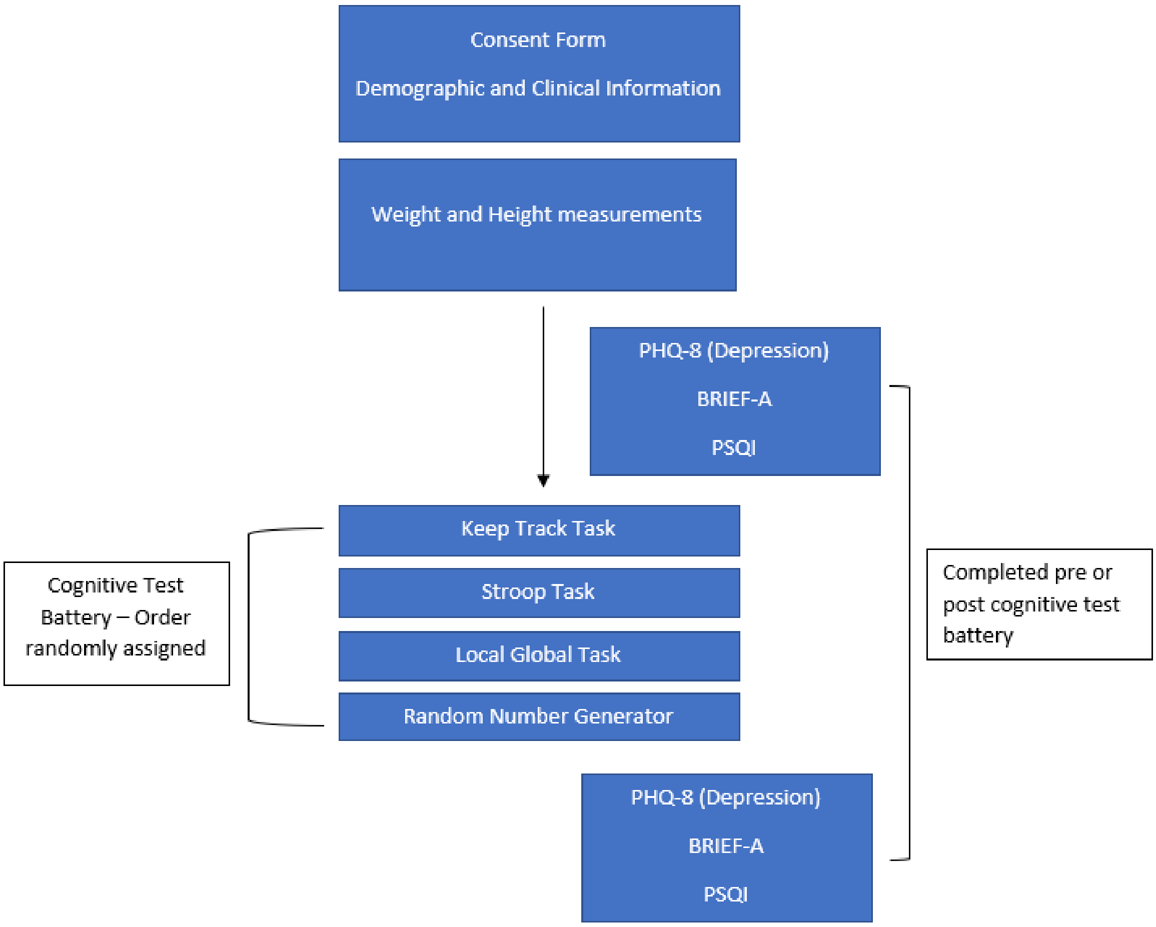

Figure 9 - Flow chart of Study Two procedure

5.9. Database Management and Data analysis

All analyses were conducted using IBM SPSS Version 25. All data which were collected were checked for discrepancies and the outputs from computer programmes were examined. Variables were appropriately coded where necessary. Data analysis took place in three analysis phases: cognitive tests, the BRIEF-A questionnaire and additional tests (UCLA and PSQI).

Quantile regression analyses were conducted to assess weight levels and the prediction of cognitive test performance whilst adjusting for potential performance changing variables. No pre analysis to assess the prevalence of missing data and deviations from normality were required.

The results presented will be for the four cognitive tests (Random Number Generator, Local-Global Difference, Stroop Difference, Keep-Track Score) with the six WHO BMI's (underweight, normal weight, overweight, obese class I, obese class III, obese class III). Data has been furthered split to show gender data across these tests and weights (total sample, male only, female only). Adjusted data will be presented with age, depression and gender being included in the analysis in tables 20, 21 and 22. To allow for these adjustments, indicators were used to account for any potential differences. Gender was represented by the female indicator for the male and female tests, when analysing the gender individually no indicators were used. Age was represented by the '46 +' which was the median score for the group. Depression was represented by an indicator representing those above a threshold and would be considered to have mild/moderate symptoms. Unadjusted data can be found in Appendix 12, 13 and 14.

The BRIEF-A questionnaire analysis was completed in two phases. Firstly, one-way analysis of variance (ANOVA) was utilised to see whether there are any statistically significant differences between the BRIEF subscales and the BMI weight groups with post hoc tests. Lastly, correlations to measure the strength and direction of any associations between the BRIEF-A 'components' and the cognitive tests were assessed using the Kendall's tau-b correlation coefficient.

Demographics and ANOVA results presented will be for the nine BRIEF-A 'subscales' (Organisation of Materials, Emotional Control, Task Monitor, Working Memory, Inhibit, Initiate, Shift, Plan/Organise, Self monitor) with the six WHO BMI's (underweight, normal weight, overweight, obese class I, obese class III, obese class III). The correlations

(Kendall tau-b) will be presented between the BMI groups, the 4 cognitive tests and the 9 BRIEF-A subscales.

The UCLA and PSQI questionnaires were analysed via ANOVA tests. Demographics and ANOVA results presented will be for the UCLA and PSQI and the six WHO BMI's (underweight, normal weight, overweight, obese class I, obese class III, obese class III).

5.10. Results

Table 15 reports the demographics and self-reported health status among the participants. Table 16 reports on the means and standard deviations for the six BMI groups across the genders for each of the cognitive test scores (Random Number Generator, Local-Global Difference, Stroop Difference, Keep-Track Score.)

Table 15 – Health Status of Participants

		N (%)
WHO BMI category		
	Underweight (<18.5 kg/m^2)	83 (20.8%)
	Normal weight (18.5 – 24.9 kg/m^2)	87 (21.8%)
	Overweight (25.0 – 29.9 kg/m^2)	65 (16.3%)
	Obese class I (30.0 – 34.9 kg/m^2)	81 (20.3%)
	Obese class II (35.0 – 39.9 kg/m^2)	58 (14.5%)
	Obese class III (40.0> kg/m^2)	26 (6.5%)
Waist Circumference Category[1]		
	No increased risk	101 (54.0%)
	Increased risk	22 (11.8%)
	High risk	26 (13.9%)
	Very high risk	38 (20.53%)
Self-Reported measures		
	Diabetes	12
	Heart disease	2
	Asthma/Lung disease	22
	Stroke	0
	High blood pressure	2
	High Cholesterol	5
	PHQ-8[2]	59 (8.3%)

[1]WHO recommended thresholds to determine an individual's relative risk of obesity-related ill health

[2]Score of 10 or over indicating mild/moderate depressive symptoms

Table 16 - Means and SD of the cognitive tests by BMI class and gender

		Random Number Generator[1]		Local-Global Difference[2]		Stroop Difference[3]		Keep-Track Score[4]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Underweight									
	Total n=83	6.83	1.02	-87.20	791.75	-13.71	652.48	8.41	2.70
	Male n=42	6.80	1.02	-33.92	862.59	-45.33	630.93	8.33	2.66
	Female n=41	6.84	1.03	-141.68	718.60	18.68	680.15	8.49	2.78
Normal weight									
	Total n=87	6.82	1.01	-41.97	644.87	12.95	649.93	9.07	2.98
	Male n=38	6.90	1.04	-174.95	662.02	-109.27	642.43	8.76	2.94
	Female n=49	6.76	1.00	61.15	618.38	107.74	646.28	9.31	3.02
Overweight									
	Total n=65	6.92	.89	71.84	657.38	-15.18	643.10	7.91	2.90
	Male n=31	6.80	.78	-12.10	567.94	-31.73	678.37	7.58	2.81
	Female n=34	7.02	.98	148.37	729.54	-.10	619.07	8.21	2.99
Obese Class I									
	Total n=81	6.91	1.04	43.04	776.25	32.92	681.83	8.90	3.03
	Male n=34	7.06	1.04	51.60	823.05	101.39	667.38	9.35	2.93
	Female n=47	6.79	1.03	36.86	749.59	-16.60	694.99	8.57	3.09
Obese Class II									
	Total n=58	6.84	.94	-224.31	894.37	-36.45	623.79	8.19	3.05
	Male n=29	6.86	.92	-160.24	897.14	45.27	715.06	9.00	3.25
	Female n=29	6.84	.98	-288.38	902.71	-118.17	526.71	7.38	2.65
Obese Class III									
	Total n=26	6.80	.83	-113.53	686.00	45.94	665.24	7.92	2.17
	Male n=11	6.63	.78	-145.46	624.92	-60.98	683.81	8.55	2.02
	Female n=14	6.97	.89	58.57	495.92	198.17	621.75	7.36	2.27

[1] A high score = better performance. [2]Local-Global Difference = Local-Global Conflicting - Local-Global Consistent. A high score = worse performance.

[3] Stroop Task Difference = Stroop Incongruent – Stroop Congruent. A high score = worse performance. [4] A high score = better performance.

5.11. Adjusted results

For all of the quantile regression results comparisons were made against the normal weight scores. Regression results are provided for male only, female only and gender combined data across three quantiles; lower, median and upper. Quantile regression scores can be found in tables 17, 18 and 19.

Each of the tables include the BMI estimates, standard error values, 95% confidence intervals and p-values. Data are presented for males only, females only and combined male and female data. Table 17 shows the adjusted quantile regressions scores for the lower quartile across all four of the cognitive measures. Table 18 shows the adjusted quantile regressions scores for the median quartile across all four of the cognitive measures. Table 19 shows the adjusted quantile regressions scores for the upper quartile across all four of the cognitive measures.

5.11.1. Random Number Generator

Quantile regression results for the Random Number Generator scores revealed no significant differences between the BMI weight groups across the quantiles and between the gender groups.

5.11.2. Local-Global Task

The Local-Global difference scores for the upper quartile show that reduced performance was shown in the obese class I groups for both the combined data ($F(390)=1.99$, $p=.048$) and the female only dataset ($F(177)=2.30$, $p=023$).

Also in the upper quartile, the overweight groups performance reveals poorer performance scores for females ($F(206)=2.62$, $p=.010$). No further significant data was shown across the quartiles for the BMI groups or gender groups. Overall significant results showed that the obese class II group performed significantly worse on this task along with the overweight group, responding slower to inconsistent stimuli.

5.11.3. Stroop Task

Quantile regression results for the Stroop task scores revealed that those who were in the obese class II were significantly better at performing the task ($F(206)=-2.29$, $p=.023$). No other significant differences between the BMI weight groups across the quantiles and between the gender groups were found.

5.11.4. Keep-Track Task

The Keep-Track scores revealed that across the data for the median quartile scores performance was significantly worse for the overweight group for both the combined ($F(390)=-2.30$, $p=.022$) and the female groups ($F(206)=-2.48$, $p=.014$). Significant results were found for the upper quartile scores. With the combined male and female data revealing poorer updating performance for the overweight ($F(390)=-3.53$, $p<.001$) and obese class III ($F(390)=-2.56$, $p=.011$) groups. This is reflected in the female only data with the overweight ($F(206)=-2.92$, $p=.004$) and obese class III ($F(206)=-2.76$, $p=.006$) groups performing significantly worse. In addition to this the obese class II ($F(206)=-2.1$, $p=.031$) group also performed significantly worse. A further significant result was found in the upper quartile female only group where those with an increased age had a better performance ($F(206)=2.24$, $p=.026$). Overall the overweight, obese class II and the class III obese groups performed significantly worse on this task, recalling less words than the other weight groups.

Table 17 - Adjusted quantile regressions of the lower quartile for the four cognitive measures

	Total n=400					Males only n=185					Females only n=214				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	6.02	0.16	5.71	6.33	0.000	6.00	0.20	5.61	6.39	0.000	6.04	0.20	5.64	6.44	0.000
Underweight	0.03	0.19	-0.35	0.41	0.875	0.00	0.26	-0.52	0.52	1.000	0.00	0.27	-0.54	0.54	1.000
Overweight	0.25	0.20	-0.15	0.65	0.221	0.25	0.28	-0.31	0.81	0.378	0.47	0.29	-0.10	1.04	0.104
Obese Class I	0.05	0.19	-0.33	0.43	0.794	0.34	0.28	-0.20	0.88	0.218	0.01	0.26	-0.51	0.53	0.970
Obese Class II	0.30	0.21	-0.11	0.71	0.155	0.35	0.29	-0.22	0.92	0.227	-0.04	0.30	-0.64	0.56	0.896
Obese Class III	0.05	0.28	-0.50	0.60	0.859	0.07	0.40	-0.72	0.86	0.862	0.22	0.39	-0.54	0.98	0.570
Age (46+)	-0.02	0.12	-0.27	0.23	0.873	0.00	0.19	-0.37	0.37	1.000	-0.26	0.19	-0.63	0.11	0.167
Gender (Female)	-0.05	0.13	-0.31	0.21	0.708										
Depression	-0.15	0.25	-0.64	0.34	0.549	-0.42	0.39	-1.18	0.34	0.277	0.10	0.33	-0.54	0.74	0.760
Local-Global Difference															
Intercept	-463.28	129.74	-718.35	-208.21	0.000	-514.20	173.81	-857.21	-171.19	0.004	-189.47	164.59	-513.96	135.02	0.251
Underweight	-281.39	156.30	-588.69	25.92	0.073	-240.63	230.41	-695.33	214.07	0.298	-425.48	218.25	-855.77	4.81	0.053
Overweight	-7.63	167.18	-336.32	321.06	0.964	103.22	249.82	-389.78	596.22	0.680	-317.14	230.89	-772.35	138.07	0.171
Obese Class I	-217.95	156.96	-526.53	90.63	0.166	-117.88	242.90	-597.24	361.48	0.628	-376.93	210.15	-791.25	37.39	0.074
Obese Class II	-274.72	172.43	-613.72	64.29	0.112	-209.69	255.04	-713.01	293.63	0.412	-418.81	244.24	-900.34	62.72	0.088
Obese Class III	-77.34	230.59	-530.69	376.02	0.738	-185.76	355.53	-887.38	515.86	0.602	-221.43	310.58	-833.75	390.89	0.477
Age (46+)	129.72	102.40	-71.61	331.04	0.206	193.96	167.29	-136.17	524.09	0.248	190.34	150.42	-106.22	486.90	0.207
Gender (Female)	181.57	109.39	-33.51	396.64	0.098										
Depression	-227.72	204.65	-630.06	174.63	0.267	-343.09	340.16	-1014.39	328.21	0.315	82.78	262.45	-434.64	600.20	0.753
Stroop Difference															
Intercept	-583.02	125.47	-829.70	-336.34	0.000	-611.39	174.06	-954.89	-267.89	0.001	-443.71	134.96	-709.78	-177.64	0.001
Underweight	74.25	151.16	-222.94	371.44	0.624	228.83	230.74	-226.52	684.18	0.323	-129.57	178.96	-482.39	223.25	0.470
Overweight	29.52	161.68	-288.35	347.39	0.855	186.03	250.18	-307.68	679.74	0.458	-89.87	189.32	-463.13	283.39	0.636
Obese Class I	130.02	151.79	-168.41	428.45	0.392	311.67	243.25	-168.38	791.72	0.202	-70.90	172.31	-410.63	268.83	0.681
Obese Class II	-25.26	166.75	-353.11	302.59	0.880	291.36	255.41	-212.68	795.40	0.256	-64.03	200.27	-458.87	330.81	0.750
Obese Class III	41.12	223.00	-397.32	479.56	0.854	130.60	356.04	-572.03	833.23	0.714	74.66	254.67	-427.43	576.75	0.770
Age (46+)	100.54	99.03	-94.16	295.24	0.311	16.74	167.53	-313.86	347.34	0.921	170.02	123.34	-73.15	413.19	0.170
Gender (Female)	170.02	105.80	-37.98	378.02	0.109										
Depression	-105.40	197.91	-494.51	283.71	0.595	-295.73	340.65	-967.99	376.53	0.386	-105.40	215.20	-529.67	318.87	0.625
Keep-Track															
Intercept	7.00	0.66	5.70	8.30	0.000	7.00	0.75	5.52	8.48	0.000	6.50	0.73	5.06	7.94	0.000
Underweight	0.00	0.79	-1.56	1.56	1.000	-1.00	0.99	-2.96	0.96	0.314	0.00	0.97	-1.91	1.91	1.000

Overweight	0.00	0.85	-1.67	1.67	1.000	0.00	1.07	-2.12	2.12	1.000	0.00	1.03	-2.02	2.02	1.000
Obese Class I	0.00	0.80	-1.57	1.57	1.000	1.00	1.05	-1.06	3.06	0.340	0.00	0.93	-1.84	1.84	1.000
Obese Class II	-1.00	0.88	-2.72	0.72	0.255	-1.00	1.10	-3.17	1.17	0.363	-0.50	1.09	-2.64	1.64	0.646
Obese Class III	-1.00	1.17	-3.31	1.31	0.394	-1.00	1.53	-4.02	2.02	0.514	-1.50	1.38	-4.22	1.22	0.279
Age (46+)	0.00	0.52	-1.02	1.02	1.000	1.00	0.72	-0.42	2.42	0.166	1.50	0.67	0.18	2.82	0.026
Gender (Female)	1.00	0.56	-0.09	2.09	0.073										
Depression	-1.00	1.04	-3.05	1.05	0.337	1.00	1.46	-1.89	3.89	0.495	-0.50	1.17	-2.80	1.80	0.669

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Table 18 - Adjusted quantile regressions of the median quartile for the four cognitive measures

	Total n=400					Males only n=185					Females only n=214				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	6.96	0.17	6.62	7.30	0.000	6.64	0.23	6.18	7.10	0.000	7.00	0.22	6.57	7.43	0.000
Underweight	-0.19	0.21	-0.60	0.22	0.359	0.13	0.31	-0.48	0.74	0.675	-0.23	0.29	-0.80	0.34	0.430
Overweight	0.03	0.22	-0.40	0.46	0.892	0.13	0.34	-0.53	0.79	0.699	0.02	0.31	-0.59	0.63	0.948
Obese Class I	-0.21	0.21	-0.62	0.20	0.312	0.36	0.33	-0.28	1.00	0.271	-0.27	0.28	-0.82	0.28	0.336
Obese Class II	-0.18	0.23	-0.63	0.27	0.430	0.14	0.34	-0.54	0.82	0.683	0.00	0.33	-0.64	0.64	1.000
Obese Class III	-0.21	0.31	-0.81	0.39	0.492	-0.15	0.48	-1.09	0.79	0.754	0.25	0.41	-0.57	1.07	0.547
Age (46+)	0.01	0.14	-0.26	0.28	0.941	-0.02	0.22	-0.46	0.42	0.929	-0.01	0.20	-0.41	0.39	0.960
Gender (Female)	-0.02	0.14	-0.30	0.26	0.890										
Depression	-0.50	0.27	-1.03	0.03	0.065	-0.53	0.46	-1.43	0.37	0.247	-0.38	0.35	-1.07	0.31	0.279
Local-Global Difference															
Intercept	-125.20	112.06	-345.53	95.13	0.265	-200.98	159.87	-516.49	114.53	0.210	-13.34	126.97	-263.67	236.99	0.916
Underweight	-135.00	135.01	-400.44	130.44	0.318	108.49	211.93	-309.75	526.73	0.609	-269.18	168.37	-601.13	62.77	0.111
Overweight	67.40	144.41	-216.51	351.31	0.641	139.76	229.79	-313.72	593.24	0.544	256.58	178.12	-94.60	607.76	0.151
Obese Class I	42.82	135.57	-223.73	309.37	0.752	221.42	223.43	-219.50	662.34	0.323	-63.44	162.12	-383.07	256.19	0.696
Obese Class II	-248.02	148.94	-540.84	44.80	0.097	11.59	234.60	-451.38	474.56	0.961	-269.92	188.42	-641.40	101.56	0.154
Obese Class III	129.41	199.18	-262.19	521.01	0.516	200.45	327.03	-444.92	845.82	0.541	140.55	239.60	-331.83	612.93	0.558
Age (46+)	123.00	88.45	-50.90	296.90	0.165	-66.19	153.87	-369.85	237.47	0.668	166.97	116.04	-61.81	395.75	0.152
Gender (Female)	92.80	94.49	-92.98	278.58	0.327										
Depression	373.09	176.77	25.55	720.63	0.035	-426.15	312.89	-1043.63	191.33	0.175	406.13	202.46	6.96	805.30	0.046
Stroop Difference															
Intercept	-108.92	109.98	-325.15	107.31	0.323	-112.76	130.96	-371.20	145.68	0.390	-22.10	144.20	-306.40	262.20	0.878
Underweight	134.80	132.50	-125.70	395.30	0.310	149.96	173.60	-192.63	492.55	0.389	117.99	191.22	-259.01	494.99	0.538
Overweight	69.11	141.72	-209.52	347.74	0.626	140.17	188.23	-231.29	511.63	0.457	-156.50	202.30	-555.34	242.34	0.440
Obese Class I	68.57	133.05	-193.02	330.16	0.607	72.41	183.02	-288.76	433.58	0.693	71.01	184.12	-291.99	434.01	0.700
Obese Class II	45.62	146.17	-241.75	332.99	0.755	195.29	192.16	-183.94	574.52	0.311	-103.12	213.99	-525.02	318.78	0.630
Obese Class III	177.19	195.47	-207.12	561.50	0.365	-12.76	267.88	-541.40	515.88	0.962	264.15	272.12	-272.34	800.64	0.333
Age (46+)	16.42	86.81	-154.24	187.08	0.850	4.15	126.04	-244.59	252.89	0.974	30.50	131.79	-229.34	290.34	0.817
Gender (Female)	79.35	92.73	-102.97	261.67	0.393										
Depression	21.23	173.48	-319.84	362.30	0.903	276.83	256.30	-228.96	782.62	0.282	-113.02	229.94	-566.36	340.32	0.624
Keep-Track															
Intercept	9.00	0.33	8.36	9.64	0.000	9.00	0.56	7.90	10.10	0.000	9.00	0.54	7.93	10.07	0.000
Underweight	0.00	0.39	-0.77	0.77	1.000	0.00	0.74	-1.45	1.45	1.000	-1.00	0.72	-2.42	0.42	0.167

Overweight	0.00	0.42	-0.83	0.83	1.000	0.00	0.80	-1.58	1.58	1.000	0.00	0.76	-1.50	1.50	1.000
Obese Class I	0.00	0.40	-0.78	0.78	1.000	0.00	0.78	-1.53	1.53	1.000	0.00	0.69	-1.37	1.37	1.000
Obese Class II	-1.00	0.43	-1.85	-0.15	0.022	0.00	0.82	-1.61	1.61	1.000	-2.00	0.81	-3.59	-0.41	0.014
Obese Class III	-1.00	0.58	-2.14	0.14	0.086	-1.00	1.14	-3.24	1.24	0.380	-2.00	1.03	-4.02	0.02	0.053
Age (46+)	0.00	0.26	-0.51	0.51	1.000	0.00	0.53	-1.06	1.06	1.000	0.00	0.50	-0.98	0.98	1.000
Gender (Female)	0.00	0.28	-0.54	0.54	1.000										
Depression	0.00	0.52	-1.01	1.01	1.000	1.00	1.09	-1.15	3.15	0.359	0.00	0.87	-1.71	1.71	1.000

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Table 19 - Adjusted quantile regressions of the upper quartile for the four cognitive measures

	Total n=400					Males only n=185					Females only n=214				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	7.59	0.20	7.20	7.98	0.000	7.58	0.24	7.10	8.06	0.000	7.58	0.26	7.07	8.09	0.000
Underweight	-0.08	0.24	-0.55	0.39	0.737	-0.07	0.32	-0.70	0.56	0.827	0.04	0.34	-0.63	0.71	0.906
Overweight	-0.01	0.26	-0.51	0.49	0.969	-0.33	0.35	-1.02	0.36	0.344	0.17	0.36	-0.54	0.88	0.637
Obese Class I	0.26	0.24	-0.21	0.73	0.278	0.32	0.34	-0.35	0.99	0.345	-0.17	0.33	-0.82	0.48	0.604
Obese Class II	-0.15	0.26	-0.67	0.37	0.569	-0.12	0.35	-0.82	0.58	0.736	-0.23	0.38	-0.98	0.52	0.546
Obese Class III	-0.07	0.35	-0.76	0.62	0.842	-0.09	0.49	-1.07	0.89	0.856	0.08	0.48	-0.87	1.03	0.869
Age (46+)	0.00	0.16	-0.31	0.31	1.000	0.00	0.23	-0.46	0.46	1.000	0.05	0.23	-0.41	0.51	0.831
Gender (Female)	-0.04	0.17	-0.37	0.29	0.811										
Depression	-0.60	0.31	-1.21	0.01	0.055	-0.24	0.47	-1.17	0.69	0.613	-0.83	0.41	-1.64	-0.02	0.044
Local-Global Difference															
Intercept	312.40	133.00	50.92	573.88	0.019	293.73	186.45	-74.21	661.67	0.117	295.75	117.55	64.00	527.50	0.013
Underweight	36.75	160.23	-278.27	351.77	0.819	346.97	247.16	-140.78	834.72	0.162	-101.82	155.87	-409.13	205.49	0.514
Overweight	283.81	171.38	-53.13	620.75	0.099	84.04	267.98	-444.80	612.88	0.754	431.68	164.90	106.57	756.79	0.010
Obese Class I	319.54	160.90	3.21	635.87	0.048	598.25	260.56	84.05	1112.45	0.023	243.94	150.09	-51.96	539.84	0.106
Obese Class II	-123.11	176.76	-470.62	224.40	0.487	425.47	273.59	-114.44	965.38	0.122	-221.78	174.44	-565.69	122.13	0.205
Obese Class III	-18.56	236.38	-483.30	446.18	0.937	69.78	381.38	-682.85	822.41	0.855	2.25	221.81	-435.07	439.57	0.992
Age (46+)	4.16	104.97	-202.22	210.54	0.968	-217.53	179.45	-571.66	136.60	0.227	147.51	107.43	-64.29	359.31	0.171
Gender (Female)	74.02	112.14	-146.46	294.50	0.510										
Depression	169.18	209.79	-243.27	581.63	0.420	-409.00	364.89	-1129.10	311.10	0.264	316.35	187.44	-53.19	685.89	0.093
Stroop Difference															
Intercept	391.55	125.41	144.97	638.12	0.002	315.50	169.38	-18.76	649.76	0.064	519.61	140.90	241.81	797.41	0.000
Underweight	62.91	151.09	-234.15	359.97	0.677	48.74	224.53	-394.36	491.84	0.828	84.15	186.84	-284.22	452.52	0.653
Overweight	-51.06	161.61	-368.79	266.67	0.752	-51.06	243.44	-531.49	429.37	0.834	-62.34	197.67	-452.05	327.37	0.753
Obese Class I	92.30	151.73	-206.00	390.60	0.543	241.98	236.71	-225.15	709.11	0.308	-168.70	179.91	-523.40	186.00	0.349
Obese Class II	-59.44	166.68	-387.14	268.26	0.722	205.00	248.54	-285.48	695.48	0.411	-479.36	209.10	-891.60	-67.12	0.023
Obese Class III	43.10	222.91	-395.15	481.35	0.847	-148.05	346.46	-831.77	535.67	0.670	113.38	265.89	-410.83	637.59	0.670
Age (46+)	82.62	98.99	-111.99	277.24	0.404	114.54	163.02	-207.17	436.25	0.483	81.68	128.78	-172.21	335.57	0.527
Gender (Female)	38.49	105.75	-169.42	246.40	0.716										
Depression	219.29	197.83	-169.65	608.23	0.268	295.34	331.49	-358.83	949.51	0.374	-18.62	224.68	-461.59	424.35	0.934
Keep-Track															
Intercept	11.00	0.44	10.14	11.86	0.000	11.00	0.75	9.52	12.48	0.000	11.00	0.49	10.04	11.96	0.000
Underweight	-1.00	0.53	-2.04	0.04	0.060	-1.00	0.99	-2.96	0.96	0.314	0.00	0.65	-1.28	1.28	1.000

Overweight	-2.00	0.57	-3.11	-0.89	0.000	-2.00	1.07	-4.12	0.12	0.064	-2.00	0.68	-3.35	-0.65	0.004
Obese Class I	0.00	0.53	-1.05	1.05	1.000	0.00	1.05	-2.06	2.06	1.000	0.00	0.62	-1.23	1.23	1.000
Obese Class II	-1.00	0.58	-2.15	0.15	0.088	0.00	1.10	-2.17	2.17	1.000	-2.00	0.72	-3.43	-0.57	0.006
Obese Class III	-2.00	0.78	-3.54	-0.46	0.011	-1.00	1.53	-4.02	2.02	0.514	-2.00	0.92	-3.82	-0.18	0.031
Age (46+)	0.00	0.35	-0.68	0.68	1.000	0.00	0.72	-1.42	1.42	1.000	0.00	0.45	-0.88	0.88	1.000
Gender (Female)	0.00	0.37	-0.73	0.73	1.000										
Depression	1.00	0.69	-0.36	2.36	0.150	0.00	1.46	-2.89	2.89	1.000	0.00	0.78	-1.53	1.53	1.000

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Table 20 - Sleep and Loneliness means and standard deviations

	Pittsburgh Sleep Quality Index (PSQI) Global Score[1]		UCLA Three-Item Loneliness Scale[2]	
	Mean	SD	Mean	SD
Underweight	2.71	1.20	3.95	.97
Normal weight	3.33	1.20	3.23	.44
Overweight	2.88	1.36	3.73	1.03
Obese Class I	2.91	1.22	3.90	1.24
Obese Class II	3.26	1.32	3.27	.47
Obese Class III	3.04	1.18	3.60	.89

[1] Seven component scores are summed to produce a global score. Higher scores indicate worse sleep quality.

[2] Three items totalled. Higher scores indicate greater degrees of loneliness.

5.12. *UCLA Loneliness Scale*

There were a small number of outliers in the data, as assessed by inspection of a boxplot. The UCLA overall score was not normally distributed for the BMI weight groups as assessed by Shapiro-Wilk's test ($p < .05$). The assumption of homogeneity of variances was violated as assessed by Levene's test for equality of variances ($p = .016$). A one-way Welch ANOVA found there were no statistically significant differences in UCLA overall score between the different BMI groups, Welch's $F(5, 25.18) = 2.44$, $p = .062$. Means and standard deviations can be found in Table 20.

5.13. *The Pittsburgh Sleep Quality Index*

There were a small number of outliers in the data, as assessed by inspection of a boxplot. The PSQI overall score was not normally distributed for the BMI weight groups as assessed by Shapiro-Wilk's test ($p < .05$). There was homogeneity of variances as assessed by Levene's test for equality of variances ($p = .193$). A one-way ANOVA found that the quality and patterns of sleep in adults was statistically significantly different for different BMI weight groups, $F(5, 394) = 2.83$, $p = .016$. There was an increase in PSQI scores from the normal weight group ($M = 3.33$, $SD = 1.20$) to the underweight group ($M = 2.71$, $SD = 1.21$) which was statistically significant ($p = .016$). This would indicate normal weight individuals had worse sleep quality compared to the underweight group. However, this score is not above the minimum 5 score threshold which would indicate acute sleep disturbances. Means and standard deviations can be found in Table 20.

Table 21 - Means and SD of the BRIEF-A subscales by BMI class together with p-value from a one-way ANOVA

	Underweight		Normal weight		Overweight		Obese Class I		Obese Class II		Obese Class III		p-value
	Raw Score	T-score	Raw Score	T-score	Raw Score	T-score	Raw Score	T-score	Raw Score	T-score	Raw Score	T-score	
Organisation of materials	1.58 (.29)	50.63 (4.87)	1.58 (.34)	50.52 (4.50)	1.59 (.35)	50.62 (3.94)	1.55 (.25)	50.49 (4.47)	1.56 (.29)	50.40 (3.75)	1.64 (.40)	50.23 (4.44)	.812
Emotional control	1.49 (.18)	50.73 (4.91)	1.51 (.15)	50.93 (4.63)	1.53 (.16)	50.86 (4.43)	1.51 (.13)	49.98 (4.94)	1.52 (.14)	50.84 (4.11)	1.54 (.17)	50.69 (4.86)	.558
Task monitor	1.48 (.20)	48.89 (3.50)	1.48 (.22)	49.41 (3.15)	1.49 (.22)	49.62 (3.05)	1.47 (.23)	49.09 (2.46)	1.48 (.20)	49.40 (2.83)	1.49 (.21)	50.08 (3.44)	.995
Working memory	1.55 (.28)	49.20 (4.32)	1.62 (.31)	49.49 (4.27)	1.56 (.29)	49.05 (4.21)	1.56 (.23)	48.02 (4.14)	1.58 (.28)	49.79 (4.96)	1.67 (.31)	50.04 (4.74)	.242
Inhibit	1.44 (.19)	51.54 (4.97)	1.43 (.16)	51.48 (5.59)	1.44 (.15)	50.74 (4.94)	1.44 (.18)	52.80 (4.53)	1.43 (.14)	51.05 (4.20)	1.41 (.16)	52.31 (7.51)	.965
Initiate	1.53 (.19)	54.48 (7.15)	1.51 (.21)	56.64 (7.56)	1.50 (.20)	54.72 (7.24)	1.58 (.17)	54.75 (5.98)	1.49 (.16)	55.43 (7.09)	1.54 (.25)	57.88 (7.80)	.051
Shift	1.52 (.23)	51.55 (4.16)	1.52 (.21)	52.30 (4.90)	1.52 (.19)	51.65 (4.21)	1.49 (.21)	51.17 (3.63)	1.52 (.18)	51.36 (4.74)	1.51 (.22)	52.08 (4.79)	.826
Plan/organise	1.51 (.15)	50.64 (5.05)	1.53 (.20)	51.01 (5.66)	1.51 (.16)	50.83 (5.36)	1.50 (.17)	50.37 (6.11)	1.49 (.20)	50.76 (5.02)	1.51 (.18)	51.12 (5.31)	.835
Self-monitor	1.51 (.19)	49.39 (5.78)	1.51 (.20)	49.83 (6.68)	1.50 (.18)	49.54 (6.90)	1.46 (.20)	48.85 (4.78)	1.53 (.23)	49.31 (5.82)	1.53 (.22)	51.00 (7.88)	.333

5.14. The Behaviour Rating Inventory of Executive Function

There were a number of outliers in the data across the BRIEF-A scales as assessed by inspection of the boxplots. Each of the BRIEF-A scales were not normally distributed for the BMI weight groups as assessed by Shapiro-Wilk's test ($p < .05$). For the organisation of materials scale there was homogeneity of variances as assessed by Levene's test for equality of variances ($p = .077$). A one-way ANOVA found that there were no statistical differences between the BMI weight groups, $F(5, 394) = .452$, $p = .812$. For the emotional control scale, the assumption of homogeneity of variances was violated, as assessed by Levene's test for equality of variances ($p = .008$). A one-way Welch ANOVA found there were no statistically significant differences between the different BMI groups, Welch's $F(5, 141.771) = .647$, $p = .664$. For the task monitor scale there was homogeneity of variances as assessed by Levene's test for equality of variances ($p = .745$). A one-way ANOVA found that there were no statistical differences between the BMI weight groups, $F(5, 394) = .080$, $p = .995$. For the working memory scale there was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .526$). A one-way ANOVA found that there were no statistical differences between the BMI weight groups, $F(5, 394) = 1.35$, $p = .242$. For the inhibit scale there was homogeneity of variances as assessed by Levene's test for equality of variances ($p = .289$). A one-way ANOVA found that there were no statistical differences between the BMI weight groups, $F(5, 394) = .195$, $p = .965$. For the initiate scale there was homogeneity of variances as assessed by Levene's test for equality of variances ($p = .136$). A one-way ANOVA found that there were no statistical differences between the BMI weight groups, $F(5, 394) = 2.23$, $p = .051$. For shift scale there was homogeneity of variances as assessed by Levene's test for equality of variances ($p = .411$). A one-way ANOVA found that there were no statistical differences between the BMI weight groups, $F(5, 394) = .432$, $p = .826$. For the planning / organise scale there was homogeneity of variances as assessed by Levene's test for equality of variances ($p = .274$). A one-way ANOVA found that there were no statistical difference between the BMI weight groups, F(5, 394) = 1.15, p = .333. Means and standard deviations can be found in Table 21.

Table 22 - Non-parametric correlations (Kendell tau-b) between BMI and the four cognitive tests and BMI and nine BRIEF-A subscales

	Correlation	p-value
Cognitive tests:		
Random Number Generation	.008	.818
Local-Global Task	.001	.969
Stroop Task	-.001	.985
Keep-Track Task	-.038	.319
BRIEF-A :		
Organisation of materials	-.007	.854
Emotional control	.023	.563
Task monitor	-.013	.742
Working memory	.052	.187
Inhibit	-.021	.596
Initiate	.032	.411
Shift	-.020	.613
Plan/organise	-.031	.434
Self monitor	-.008	.843

Kendall's tau-b correlations were run to determine the relationship between BMI and the four cognitive tests and nine BRIEF-A subscales. None of the pairings were statistically significant. Correlation results can be found in Table 22.

5.15. Waist Circumference.

Table 23 reports the means, standard deviations and p values for the waist circumference risk groups. For the random number generation task there were homogeneity of variances as assessed by Levene's test for equality of variances (p = .480). A one-way ANOVA found that there were no statistical differences between the waist circumference risk groups, F(3, 183) = .389, p = .761. For the Local-Global task there were homogeneity of variances as assessed by Levene's test for equality of variances (p = .944). A one-way ANOVA found that there were no statistical differences between the waist circumference risk groups, F(3, 183) = 1.695, p = .170. For the Stroop task there were homogeneity of variances as assessed by Levene's test for equality of variances (p = .518). A one-way ANOVA found that there were no statistical differences between the waist circumference risk groups, $F(3, 183) = .052$, $p = .984$.

For the Keep-Track task there were homogeneity of variances as assessed by Levene's test for equality of variances ($p = .809$). A one-way ANOVA found that there was statistical difference between the waist circumference risk groups, $F(3, 183) = 4.575$, $p = .004$. Tukey post hoc analysis revealed that task performance was poorer for the high-risk group compared to the no increased risk group and this was statistically significant ($p = .038$). The high-risk group also performed significantly worse than the increased risk groups ($p=.004$).

Table 23 - Means and SD of the cognitive tasks by waist circumference risk together with p-value from a one-way ANOVA

	No Increased Risk	Increased Risk	High Risk	Very High Risk	p-value
n	101	22	26	38	
Random Number Generation[1]	7.00 (.96)	7.13 (1.03)	6.84 (1.12)	6.92 (.86)	.761
Local-Global Task[2]	-79.04 (698.46)	170.91 (741.10)	147.00 (727.98)	-196.83 (951.71)	.170
Stroop Task[3]	25.88 (628.08)	61.37 (737.21)	11.12 (701.74)	-5.11 (624.76)	.984
Keep-Track Task[4]	8.80 (2.72)	7.68 (3.23)	10.46 (2.66)	8.34 (2.83)	.004

[1] A high score = better performance.
[2]Local-Global Difference = Local-Global Conflicting - Local-Global Consistent. A high score = slower performance.
[3] Stroop Task Difference = Stroop Incongruent – Stroop Congruent. A high score = slower performance.
[4] A high score = better performance.

5.16. Discussion

Several key findings emerged from this investigation. Firstly, the relationship between weight and executive functions was not replicated from Study One. There were few differences across the cognitive tests, the weight classifications and between the gender groups. Secondly, there were no associations found between the self-rating BRIEF-A test and the performance based cognitive tests. Finally, no differences were found between the weight groups on tests of loneliness, with no above threshold differences found between the weight groups on a test of sleep quality.

The Study Two cognitive results were unexpected, the data provided very little differences between the weight groups compared to Study One. Only two findings were replicated across both studies: poor performance by the obese class III group on the updating task and poor performance by the obese class II groups on the switching task in comparison to the other groups. The test of updating the effect of the larger obese groups fell in line with Stingl et al. (2012) and Cohen et al. (2011), both finding differences between the obese and normal weight groups supporting Study One. It would have been expected that the number of differences across the switching, inhibition and updating executive functions would have been reflected in this dataset. The samples used in this study were not matched for those in Study One but were from a very similar population utilising the same business, community and student centres. Therefore, it was hypothesised that similar findings would be replicated but this was the not the case.

It remains unclear why the results were not replicated. The lack of differences may be related to the assessment of the executive functions. This had its limitations; it required the researcher to set-up and complete the testing in an environment which was not controlled. In fact a number of different environments were utilised to complete the studies. The inconsistent environments could be a reason for the differing results but there are other potential variables which could account for these differences.

Across both studies a participant's intentions to restrain food intake or diet were not assessed. This could be a possible reason for the differences between these populations, in that individuals may have been dieting or lost weight prior to their participation in the study which could have affected their performance on tasks of executive functions (Deckers et al., 2017). Holloway et al. (2011) found that cognitive function may be influenced by dieting habits, in that those on a controlled high fat, low carbohydrate diet were negatively impacted on cognitive tests compared to a standard balanced diet group. Interestingly this poor performance could occur after just five days of switching to the high fat, low carbohydrate diet with the changes being reversed after a two-week period. There is the potential that within this current study population the groups differing dieting status has revealed unexpected results. This reasoning may also account for other studies which have found limited or no differences between the weight groups. In some clinical studies where patients are recruited through clinics for bariatric surgery or eating disorders, food intake for patients is not always accounted in the study data. It may be expected that due to the nature of their recruitment they would be on some form of diet at the time of them participating in the research. This could have the potential to influence results and may account for the lack of differences between the weight groups (Dassen et al., 2018; Schiff et al., 2016; Van der Oord et al., 2018).

The difference in the underweight groups across both studies may be due to medical or psychological conditions such as an eating disorder which were not measured within the study populations. In line with previous studies it was expected that weight classification justifications would be provided from the self-report demographic sheet which was completed by participants. Weight at either end of the scale has been linked to a number of chronic health conditions including diabetes (Hauner et al., 2016), cardiovascular disease (Poirier & Eckel, 2002) and impaired glucose intolerance (Jauch-Chara et al., 2011). However, this self-report methodology revealed very little across both studies and an insight into psychological conditions would have been useful. A possible reason for the underweight observations could still be in relation to diet. It has been observed that weight recovery in underweight individuals can improve cognitive function which may be something which has been detected in the current study (Lozano-Serra et al., 2014).

The data follows the similar pattern of some research which has not found the differences between the weight groups. Ariza et al. (2012) recruited a community-based population from local public medical centres with a mix of men and women. This research group considered inhibition, updating and shifting and found no significant group differences across the tests. Likewise, Van der Oord et al. (2018), a bariatric clinical study also found no differences across all the executive functions, concluding that it is not obesity alone which causes individuals to have cognitive disadvantages. Bonger et al. (2015) also a community based study recruited a larger sample (n=319) with a mixed gender population. They found no difference on tests of inhibition, with significant results only reflected through self-report methodologies.

Although there are limited differences compared to the previous study, some significant results were found for the task of updating with the overweight, obese class II and obese class III performing worse. These differences for this task are also reflected in the waist circumference data where the high-risk group underperformed compared to the no risk and increased risk group. This potentially shows that this updating task can map on to both waist circumference and BMI based data.

In addition, to this the obese class I and overweight groups underperformed compared to the other weight groups on the switching task. This supports and compares to Study One where differences are seen on tasks in the obese class III groups. The differences within the obese class II and overweight groups further supports work which separates these classifications rather than having the overweight and obese categories grouped together. Within this population there is potentially something which impacts the overweight and obese II groups. Given the time limits of testing it would not have been possible to screen for all potential confounds and there may have been some unreported and undetected factors such as Dyslexia and Attention Deficit Hyperactivity Disorder (ADHD) which are known to negatively impact performance on some tasks (Nigg, 2011).

For the BRIEF-A subscales in the current studies, no significant differences were found in the self-reported answers across the BMI weight groups. Normative scores were similar to those from other adult populations (Tatsi et al., 2020). This clinical rating scale has found no clear difference in real world executive functions when analysed for weight within this population. Taking into account the findings from Study One's cognitive results it may have been expected that some differences would have been found particularly in the underweight and obese categories. This can only be predicted if it is believed that cognitive tests and self-reported measures are to be a reflection of each and therefore similar results would be expected. In the case of Study Two where limited cognitive differences have been found, the non-significant BRIEF-A results may well reflect this. However, correlation results have highlighted no associations between any of the cognitive or BRIEF-A subscales across BMI groups.

The BRIEF-A was introduced due to the complexities of executive function and the belief that a full understanding of the concept could not be captured by cognitive tasks alone (Roth et al, 2005). Performance-based measures may not predict and allow for the true picture of cognition, the BRIEF-A provides a human element, that can capture broader and more day-to-day differences. The BRIEF-A relies upon clear cut questions which are precisely touching upon the subscale that they are associated with. For the performance based cognitive tests this is not the case, procedures have been created to test what we believe is an aspect of executive function. Since no relationship has been found between the tests and the BRIEF-A and with some expected cross categories, e.g. Inhibit, shifting, working memory, it is unsure which aspects of cognition they have been assessing. This supports the review of Toplak (2013), where very little work reinforced the association between self-report methods and performance based tests. Using this review as a guide it is unclear which aspects of cognition the BRIEF-A is tapping into as it may be the case that different methodologies are measuring difference levels of executive function. Furthermore, most of the self-report measures, including the BRIEF-A, have been developed in the context of clinical settings which may account for why in this community sample the measure was not as sensitive as expected.

No differences were found between BMI and the UCLA suggesting in this population there is no relationship between weight and loneliness. This is a relatively new area of investigation, with a very basic understanding of this relationship. Those who have carried out research in this area have found contradicting outcomes (Day et al., 2018; Jung and Sikorski, 2019). Loneliness is often associated with depression which is a common risk factor for obesity (Luppino et al., 2010) and in turn poor executive function. It is therefore a logical to consider both depression and loneliness when carrying out cognitive testing.

Significant differences were found between the BMI groups and the PSQI specifically the underweight and normal weight groups suggesting a poor sleep quality in those who were normal weight compared to the underweight group. There were clear differences between the groups but none which were above the minimum score threshold. With the known association between sleep and executive function performance (Resta et al., 2003; Chaput et al., 2005) this is a factor which was worth considering. Only a small number of participants in fact were above the threshold, suggesting that this population were mainly unaffected by sleep quality and its potential effects on executive function performance.

Recruiting and collecting data in the field has its positives. It allows for the recruitment of individuals who may not be easily accessible by others mean and in the case of this study has allowed for large recruitment numbers due to the researchers presence. The study was set up to create the most controlled space for testing as possible but considerations have to be made about the efficiency of these spaces. Across the three testing spaces; community, business and students, different rooms were used based upon space availability at the time of recruitment. Creating a reliable and valid testing area were of upmost importance with time taken to set up to create the same set up each time but the possibility to eradicate all distracting variables such as noise and location of rooms were difficult. This has meant that it is not guaranteed that all participants received the same experience. There are very little differences between the samples recruited in Study One and Study Two but this community experience has to be a consideration.

5.16.1. Future Research

THE BRIEF-A report would usually be served in a clinical setting with patients interpreted on an individual basis. This should be used alongside other sources including clinical interviews and informant ratings to provide an overall picture of executive function. In a clinical sense this is used to provide an effective treatment plan (Roth et al., 2005). As an extension of the current study, it would be useful to capture all of this information to provide a better picture of the impact of executive function via the BRIEF-A and its association, if any with weight. It would also be useful to recruit from a community population but test for both self-reported and performance-based methodologies in a laboratory or more controlled setting. This will then allow for a full understanding of the associations, if any with cognitive and self-reporting.

5.16.2. Implications

Cognitive tests and self-report methodologies to be used hand in hand to provide an overarching diagnosis/analysis of cognitive function. This should be continued in work across the executive functions, not just for clinical analysis. If it is true that performance based and self-report methodologies have the potential to account for different levels of executive function, then the combination of the methods should not be an afterthought but should guide future work especially that which is taking place in a community setting.

5.17. Conclusions

Overall this study has uncovered some very interesting results. It was expected that the results from Study One would be replicated. However, on a different population with similar demographics, limited significant results have been found on performance-based tests of executive function. The reasons for the differences between Study One and two will be addressed in the general discussion (Chapter 6).

Chapter 6. General Discussion of Findings

6.1. Summary of the main findings

The thesis aimed to evaluate the relationship between weight and executive function in a working aged community sample. Initially the focus was to identify whether deficits were evident and, if so, at which body mass/es, and additionally, to identify if deficits were different or consistent across three executive functions: shifting, updating and inhibition. Further to this the relationship between weight and executive function was addressed using both performance-based and self-report methodologies. An indication of the real word implications of reduced cognitive ability on weight groups was also appraised to better recognise the impact of dysfunctions on daily life and to fully appreciate the potential need to develop cognitive strategies for individuals with dysfunctions.

This was a unique contribution to the literature with a large-scale study on working aged individuals from a true community population. The two studies described throughout have demonstrated that the association between weight and executive function remains unclear for a working age community population. The systematic review results suggest that the relationship between the executive functions and the weight groups was inconsistent. In Study One, there were deficits across all three domains in underweight and obese III categories compared to the healthy weight group. In Study Two, this pattern was not replicated, as deficits were only observed in the keep track (updating) and local global (switching) tasks and not across all domains as in Study One. Furthermore, there was no evidence of deficits in the underweight group, plus the deficits in the overweight and obese groups differed from the pattern shown in Study One. The link between weight and executive function is complex. The potential factors which might contribute to the variation in the findings are described below. With a sample of over seven hundred individuals, no true association can be confirmed but this work provides the scope for future research with the focus on trying to understand the reasons for the inconsistent effects.

The thesis was unique in the way that it examined weight in its entirety, across the six BMI groups, from underweight to obese class III. As expressed within the systematic review, a majority of work within this sector has had a firm focus on overweight and obese groups compared to a baseline / normal weight group. It is potentially problematic to group overweight and obese groups together and assume that individuals cognitively perform in the same way. The work within this thesis support this, as clear differences between these groups are established with overweight individuals having some advantages over the obese group in executive function performance. Further to this, there are differences between the three obese groups with those classified as obese class III performing worse on tests of executive function compared to the other two obese groups. This shows the importance of looking across the full range of weight classifications. The studies provided an opportunity, with large-scale samples, to split these groups and reflect on them individually rather than collectively. The inclusion of an underweight group provided a chance to address executive function performance from the lowest to the highest extreme weight group.

Finally, the thesis highlighted the differences in the way that executive function is measured using performance-based and self-report measures. By exploring self-report measures the impact of cognitive deficits could be approached and a real-world representation could be considered. This was examined in Study Two where no differences were found between the BRIEF-A and the weight groups. Further to this it was found that there was a lack of association between performance-based and self-report measures within this population. Despite the limited differences the thesis conveyed how important it is to consider multiple methodologies to provide an overarching picture of executive function.

6.2. The unique contribution of the findings to the literature

6.2.1. Executive Function and BMI

The findings from this thesis provide further evidence into the differences between the weight groups across the executive function domains. Both studies explored executive function using performance based tasks and found that the link between weight and executive function is complex and inconsistent. The functions were represented by the Stroop Task (inhibition), Local-Global Task (shifting), Keep-Track Task (updating) and the Random Number Generator (complex) which are a reflection of those used in the Miyake et al. (2000) study. Very few studies account for all of the executive functions, even when citing Miyake's framework, whereas in Study One and Study Two each of the functions are represented. Despite the inconsistencies across the studies the work adds to the much-needed pool of research which is required to provide a more complete view of the role of executive function on weight. This now highlights the need to examine other factors that might account for the variance in findings across samples.

The outcomes of the studies are mixed. On the one hand, in Study One it appears that there are differences in executive function ability with an underweight, obese class II and obese class III body mass index predicting a disadvantage in task performance across the inhibition, updating and switching executive function domains. Cohen et al. (2011) and Restivo et al. (2017) utilised clinical populations and found that there were clear differences across the functions, with Stanek et al. (2013) using a community-based population to also establish these differences. As expressed above, the inclusion of a range of weights across the BMI spectrum detailed in this thesis provides an additional insight. Where previous research has made conclusions based upon overweight and obese groups as a whole, this current work is detailed enough to provide additional information about individual groups. This provides further scope and the potential to think about clinical interventions and when to consider additional weight loss help. As identified in this study, it is the higher obese classes paired with the underweight group where cognitive deficits are seen. This is a step away from the studies which have deemed overweight individuals on a par with obese groups. It can be argued from the results of this study that it is the extreme weight groups which are most affected and therefore are at a disadvantage compared to the other groups. This supports academic research literature which has shown that having an obese classification increases the likelihood of poor performance (Gameira et al., 2017; Restivo et al., 2017; Galioto et al., 2013) on these tasks and provides further evidence that overweight and obese groups should be considered independently.

Evidence of cognitive deficits in underweight participants should also be considered and why the deficits occurred in the extreme weight groups. There is the potential that the obese and underweight groups have cognitive difficulties due to the reduced ability to allocate cognitive resources to complete the tasks (Kahneman, 1973; Norman & Bobrow, 1975; Wickens, 1983). Inhibitory and behavioural control is often connected with executive function, bodyweight and feeding behaviour (Fagundo et al., 2012). Overweight and obese individuals are found to have disinhibition over food choice. Underweight individuals, anorexia nervosa specific, have been found to have high restraint over feeding behaviour linked to cognitive flexibility and inhibitory control (Batterink et al., 2010; He et al., 2014; Fagundo et al., 2012). Poor inhibitory control in obese individuals may play a part in overeating whilst someone who is underweight may be able to exert self-control. This raised behavioural control in underweight and impulsivity is often seen in cognitive tasks. Patients with anorexia nervosa have been shown to have deficits in delay discounting tasks, accepting immediate small rewards whilst delaying responses for larger rewards, resisting immediate temptation (Steinglass et al., 2017). Participants with obesity show greater discounting of delayed rewards compared to their healthy weight controls, unable to resist taking immediate rewards (Myers et al., 2020). Interestingly, Foldi et al. (2021) compared executive function deficits in obesity and anorexia nervosa and confirmed the above differences, with poor control in the obese and excessive control in those with anorexia nervosa. Further to this they also found structural and functional changes occurred in the same prefrontal cortex subregions in both groups. These results show that extreme body weight groups are using the same underlying neurobiological mechanisms, which may account for the similarities in the results for Study One.

On the other hand, Study Two provides no clear distinctions between the weight groups. Again, the academic research literature provides evidence of these lack of differences between normal weight and obese groups but the research is limited. Schiff et al. (2016) whilst exploring a clinical population and Ariza et al. (2012) using a community based population both found no differences across the functions. These previous study results generally reflect executive function as a whole. If one of the domains was not significantly impacted, the likelihood is that the rest of the domains would not be.

This similar performance pattern across each of the executive function domains, reveals that shifting, updating and inhibition abilities may not be entirely independent from one another (Miyake et al., 2000). In Study One, support of this comes from the performance on the random number generation, a complex test chosen to encompass more than one function, where results suggested that the overweight and above groups were at a disadvantage compared to the other groups. Across the board for Study One, there is support that the executive functions are mapped on to each other with Study One concluding that across the cognitive tasks results are similar.

Compared to Study One, the outcome of Study Two was unexpected. To fall in line with the overlapping theory it would have been expected that either all or no differences would be observed on the cognitive tasks. This study found that there were limited differences between the weight groups across the functions with only the updating function providing significant results. The overweight and all three classes of obesity were found to perform worse on this task, the overweight and obese class I groups were also found to be at a disadvantage on the switching task. Ultimately however, in comparison to Study One, across each of the quantiles few differences between the weight groups were observed. Further to this, the deficits were not represented in the complex task where it might be expected that a difference would have been seen. Across both studies only two findings were replicated: (1) poor performance by the obese class III group on the updating task and (2) poor performance by the obese class II groups on the switching task. This work provides an additional understanding of the complex nature of executive function in the area of weight both across the weight groups and across the individual executive functions.

This thesis provides an insight into the complexities of executive function and introduces two studies that have two differing outcomes. Demographic and health status data were mined to establish a possible reason for these differences but nothing significant was found between the two samples in relation to variables such as depression, diabetes, high blood pressure and heart disease. All of these factors have known associations with a change in executive function performance (Hauner et al., 2017; Jiang et al., 2016; Luppino et al., 2010) and perhaps would have impacted participant performance on the cognitive tasks. Other outcome measures which were not collected may have been able to account for these differences including dietary restraint which is known to affect performance on tests of executive functions (Deckers et al., 2017; Holloway et al., 2011).

6.2.2. Gender

A further variable which was considered was the gender of participants which uncovered some differences in performance between the groups. For many tasks female participants were found to be associated with significantly poorer performance when the data was analysed separately. This highlights the possibility that there are some underlying distinctions between males and females. The gender outcomes are mainly established in

Study One but interestingly the same pattern of results is also reflected in Study Two. There are fewer differences here but the majority sit within the female groups. One factor which might account for this is rumination. Rumination is a form of mind-wandering, with a focus on the causes, symptoms and consequences of distress (Minkwitz et al., 2019). The response styles theory (Nole-Hoeksema & Morrow, 1991, 1993) suggests that females tend to ruminate on their depressive symptoms more than males. This is further supported by a meta-analysis which indicated that women score higher than men in rumination, using scales such as the Rumination on Sadness Scale and Ruminative Response Scale (Johnson & Whisman, 2013). Alongside this, rumination has been associated with some executive functions including shifting and inhibition (Valenas & Szentagotai-Tatar, 2017) and higher rumination in those with obesity (Minkwitz et al., 2019). Greater rumination can lead to poorer task performance as it can take away cognitive resources which are required to perform the task. Evidence suggests that this occurs when mind-wandering is unintentional and uncontrolled (Ottaviani et al., 2015; Seli et al., 2016).

Gaillard et al. (2021) investigated sex and gender differences in the three executive domains outlined by Miyake et al. (2000) and noted that sex differences in activation of subregions of the prefrontal cortex was present in the majority of executive function tasks which were reviewed. Across the tasks, both males and females exhibited increased brain activation in these prefrontal cortex regions, which would suggest that they would be better at completing the tasks. High level activations was seen more in the male sample, suggesting males were better at completing some tasks than females or it may mean that males required greater activity in order to perform at the same level as the females (Grissom and Reyes, 2018). This was recognised across the weight groups from underweight to obese class III. The current work possibly supports this and shows that for the chosen tasks there are some underlying differences in the cognition of men and women, with males having a potential advantage over females. A possible reason for this maybe that the males within the business population have 'higher level' jobs which require more complex cognitive tasks and may be better practised in executive function domains.

6.2.3. Community-Based Population

In a non-clinical field, it is important to establish an understanding of how research can be carried out in the best and most consistent way. This thesis highlights the considerations of these thoughts and the potential impact they can have on outcomes. Much community-based work in this field has been retrospectively analysed with data being sourced from electronic databases. This thesis adds a missing step in the literature for those who are considering pursuing weight differences alongside cognitive tests. The coming together of health and cognitive psychology in a community setting has its limitations of which some be will be discussed below and have been considered in Study Two. However, moving forward a methodology to establish the suitability of cognitive tests has been determined including the considerations of ease of programming, testing time length, equipment requirement, set-up times and test accuracy.

6.2.4. Underweight Classification

One of the most important findings which was revealed throughout both studies in this thesis concerned the need to include the underweight class when considering research into weight. As discussed above there was very limited research which also included an underweight group, this was recognised in the systematic review. Previously underweight research, noted in the systematic review, had been solely clinically based with an interest in anorexia nervosa (Fagundo et al., 2012). In order to provide an overarching picture of how cognition effects the obese, it is important to see how it can affect individuals at the other end of the scale. In Study One especially, the underweight groups performed similarly to the obese groups, with the underweight and obese class III group showing deficits across the inhibition, shifting and updating functions. Although at both ends of the scale, within these populations there may be certain characteristics which are the same. Impairment in executive function in the obese and underweight categories are both associated with brain differences in gray and white matter compared to healthy normal weight individuals, impaired glucose tolerance and psychological eating related disorders (Narimani et al., 2019).

Diagnosed eating disorders with maladaptive eating styles may account for the similarities between these groups. Eating is a process which can be influenced by many factors including genetics and both social and psychological influences. Individuals have to form appropriate eating behaviours to be able to establish and maintain a healthy lifestyle (Perpina et al, 2017). When we have not been able to regulate eating behaviour appropriately this can lead to eating disorders. Anorexia nervosa and bulimia nervosa - linked with underweight groups - are examples of when negative eating behaviours can impact an individual's body weight. Eating disorders can also be a trait of those classified as obese, their weight may stem from binge-eating episodes (APA, 2013.) A common factor for both groups is poor emotional regulation. As touched upon earlier, the underweight individuals deal with this by controlling their intake whilst the obese individuals use food to distract from or control negative affect (Foldi et al., 2021). In a recent meta-analysis, this view was further established when it was highlighted that key emotional regulation difficulties were found in individuals with eating disorders (Leppanen et al., 2022).

Executive function involves a number of cognitive processes which could impact eating behaviour in an individual's everyday life. For example, those who have an inhibition impairment may find that they are unable to control what they are eating. Alternatively, being unable to shift away from the positive or negative thoughts of food could lead to making poor decisions. As uncovered in the systematic review, Schiff et al. (2016) found that those who were overweight were impulsive, they chose immediate rewards that were food related over monetary rewards which may be reflective of poor executive function which can lead to negative eating behaviours in this weight classification.

Few studies have encompassed patients that have a range of eating disorders when exploring executive functions. Studies analysed in the systematic review have incorporated these groups have found that they performed significantly worse than healthy controls (Fagundo et al. 2012; Brogan et al. 2011). Perpina et al. (2017) found impairments in cognitive flexibility and decision making in the performance on cognitive tests by the eating disorder groups (anorexia nervosa and bulimia nervosa) and obese groups compared to normal controls. The work in this thesis supports these results by showing that although it is not possible to know if individuals within the population have clinically established eating disorders, there are similarities between the underweight and extreme obese group. There is the potential that they have a shared ability or rather inability to learn, shift or inhibit in order to successfully complete a task.

Future research should attempt to account for clinical disordered eating in a community-based sample when possible. This is a very sensitive topic which in a patient environment is easy to establish with the aid of hospital notes but for a community research study it may be difficult for individuals to open up and self-report this or they may not even be aware that they have an eating disorder. Attempting to gain this insight would provide rich data on the similarities and / or differences between these groups.

6.2.5. Executive Function Measurement

The research literature reflecting on weight and executive function has neglected to account for the number of ways that executive function can be measured and the wealth of information that this can provide. This thesis has attempted to overcome this oversight where in Study Two the potential impact of executive function deficits on everyday life were explored. Further to this the differences between performance based and self-report methodologies were explored. The Behaviour Rating Inventory of Executive Function – Adult version provided this real-world link between the cognitive tests. The BRIEF-A provides a standardised and validated way to interpret how executive functions can be assessed in our everyday environment. In this thesis the BRIEF-A has not been used as a clinical assessment but has been carried out in a community-based setting which was uncomplicated and would be feasible for future studies. The self-report test allows us to capture an individual's own experiences and perspectives and is seen by the research group as a way to better appreciate and observe cognitive skill with individuals knowing more about their own behaviour than anyone else (Roth et al, 2005). This method allowed for nine different factors of executive function to be explored with relevant questions asked of participants, which in clinical setting could lead to a valid diagnosis and an effective treatment plan. No differences were found across the weight groups for the nine factors and this could be because of the community-based population which has been captured. Although the BRIEF-A can be administered by those who do not have formal clinical training, outside of the world of research this methodology is regularly used by professionals hoping to uncover some further understanding of executive function for their patient, who may likely have already exhibited some executive dysfunctions. This test may be better used and be more sensitive to these populations over a community-based one. Another factor to consider is that the overweight and obese groups may in fact have poor metacognition and may not recognise their own impairments. There are known links between executive function and metacognition with both playing an important part in cognitive development. Poor executive function is also associated with poor metacognition (Roebers, 2017). As a self-report methodology, the BRIEF-A weighs heavily on an individual being able to make assessments on their own but some may not have capacity to.

The association between the performance-based tasks and the self-report measure is also of importance. These are two different types of methodology but if they are both being used to explore the ability of executive function it would be anticipated that they would correlate in some way. With a number of aspects explored by the BRIEF-A it opened up the opportunity to look beyond the 'inhibit', 'working memory' and 'shift' factors and to see if the cognitive tests would actually map onto something else. No associations were found between the four cognitive tasks and the BRIEF-A. It shows that poor performance on a test of inhibition was not linked to the 'inhibit' factor, related to statement on the BRIEF-A such as 'People say that I am easily distracted.' It would be expected that those that were more easily distracted would demonstrate poor inhibition. It may be the case that individuals were motivated not to report deficits for fear of the consequences. This research targeted certain populations where their abilities may have been questioned. The business sample was coordinated via higher management and therefore participants may have made an assumption that any difficulties highlighted would have affected their work life, this is detailed further below. This too may be relevant to the community sample where parents and guardians dropping off their children at groups may have been conscious that their home life abilities were being questioned.

Due to the lack of differences which arose during this study, it remains unclear what everyday deficits, if any, could be captured by the BRIEF-A for this population but it has provided an insight into using the methodology. This contributes to the literature and follows on from the work by Toplak et al. (2013) who considered the association between the two methods. The combination of both of the methodologies in this thesis covered all of the bases when it came to providing a field-based representation of executive function and in a community population, where data was lacking. This should be a consideration for future studies if time allows.

6.3. Additional Considerations

Waist circumference data was an additional measure which was also analysed. Compared to the BMI groups across both of the studies, there was limited evidence to suggest that there was an association between the risk of obesity health issues, measured by waist circumference, and cognitive test performance. The updating performance in Study Two presented significant results as those who were in the risk or an increased risk groups were found to outperform the high-risk group. As with BMI, there have been inconsistent results when a waist circumference measurement has been used in association with tests of executive function. Some have found that waist circumference is not associated with any cognitive outcomes (Bugge et al, 2018). However, Decker et al. (2017) has found waist circumference to be associated with tests of executive function and to have a stronger and more widespread association with cognitive decline than BMI. As waist circumference is a risk factor for diabetes this might be an explanatory factor for this finding (Darsini et al. 2020). The Decker study was completed in a clinical setting where participants undertook a comprehensive number of medical status, lifestyle and neurocognitive measurements. In the current work for both studies, not all of the participants would allow for this measurement to be collected. This may account for the reason that, in both studies, there are many more participants classified as having 'no increased risk' compared to the other 'risk' groups. There is the possibility that those who may have been classified in these at risks groups felt only comfortable with their height and weight being measured but would not allow for their waist to be measured. The addition of this data may have provided a better understanding and it is something which should be considered for future research.

Despite accounting for waist circumference, the results from the studies have been predominantly led by the measurement of weight by BMI. However, the usefulness of BMI as a measure of ill health has been under threat and it has been suggested that BMI may not be the best indicator. Early studies, such as Prentice (2001), stated that BMI is the cornerstone for the measure of obesity however raised concerns about its appropriateness for certain groups where the body composition may actually be lean and not fat e.g. rugby players. The considerations of its suitability is further expressed by Cleator et al. (2002) who investigated whether medically significant obesity was recognised effectively in hospital outpatient departments in the United Kingdom. At this time BMI was accepted as the most appropriate index with which to define differing weight groups, with a strong correlation between BMI and the percentage of fat in populations (Duerenberg et al., 1991). Three outpatient groups retrospective data provided the comparison of a BMI measurement versus a waist circumference measurement. Interestingly for all the outpatient groups there was an increase in the prevalence of obesity when measured by waist circumference compared to when patients were measured using BMI. It was determined that opportunities to diagnose and therefore implement treatment could be missed if BMI was solely used a measurement tool. Future work should account for BMI combined with waist circumference to provide an enhanced understanding of body weight.

Burkhauser and Cawley (2008) with a focus of social science research supports the idea that BMI cannot classify obese and non-obese individuals, this more so for men over women. Interestingly they also noted that racial differences were seen when BMI was used to define obesity with African Americans more likely than White Americans to be classified as obese. A problem with BMI is that is does not distinguish between total body fat and fat free mass. NICE (2014) provides evidence-based recommendations developed by independent committees, including professional and lay members, and consulted on by stakeholders to guide healthcare in the United Kingdom. They recommend that BMI is a practical estimate of adiposity and clinicians should interpret this measurement with caution as it is not a direct measure of fatness. They also advised that waist circumference in addition to BMI with a BMI less than 35 kg/m^2 should be used. This guidance in a clinical setting should be acknowledged and followed in a research setting. There may not be a single measure of fatness with a number of elements needing to be considered to provide an accurate and representative measurement and the inclusion of other measurements including percentage body fat, waist circumferences and waist-to-hip ratio may be beneficial. BMI still has a purpose and is regularly used clinically but research indicates that we should look beyond BMI.

6.4. Strengths, limitations and future directions of the work

The main strength of this thesis was the contribution that it made to the existing weight and executive function research. At present, the literature has looked at predominantly clinical populations and older populations with female only participants, with much of the focus on performance-based measures. By collecting data from community-based participants, a wealth of rich, quantitative data was gathered. This work contributes to the methodology which may be adopted for community-based research and provides an insight into the scope of executive function testing which can be implemented. A good amount of research which has been carried out in this field and identified in the systematic review has been carried out in clinical settings with a smaller amount opting for a community-led research piece. Prior, this community research has been database led, meaning that work can be retrospective and not carried out directly by the researchers themselves. This thesis provides an alternative style of community research with cognitive tasks being taken to into a community setting. The research provides an understanding of the area outside of a clinical setting and provides data not entirely reliant on past insights. The choice of cognitive tests which were discussed in Chapter 4 (p. 69) provides thoughts on the factors which future research should consider for studies in a non-laboratory setting. This not only provides a significant contribution to the research literature but also provides a wide scope for future research in this field.

A key strength of this thesis was the use of quantile regression (Koenker et al, 1978), a relatively unused statistical approach in cognitive psychology which provided a better fit for the data. As expected, the statistical model provided a wealth of information about the effect of the predictors on the outcome. Having an understanding over a number of separate quartiles not only increases the amount of knowledge about each of the variables but it offered the possibility to address the differences between the weight groups in a more robust way, allowing for outliers and not normally distributed data, found in this thesis. This broader technique is sensitive enough to pinpoint any differences which potentially would not be established by your average mean-led statistic. This model is regularly used by ecologists and biologists (Cade and Noon, 2003) and moving forward the practise of quantile regression would be useful for social sciences especially in the use of cognition to provide a thorough depiction of the differences between and within groups. Future research should therefore aim to consider this statistical approach to gain a greater insight into executive function and other areas of cognition.

The inclusion of different methodologies and tasks to provide a fuller picture of executive function was also an advantage. The complexities and the difficulties in defining executive function as depicted in Chapter 2 of this thesis are vast. There are many facets to this area of cognition and it would be unwise to believe that a single test would be enough to provide a complete picture of these complex and demanding cognitive components. The two studies have been underpinned by the Miyake et al. (2000) executive function work which has provided not only a framework for the thesis but has driven the cognitive tests to be included in the test battery and has determined which tasks map on to specific functions. The inclusion of the self-report BRIEF-A has attempted to provide an additional layer of understanding and accounts for the potential of executive function to be more dynamic than first thought. This area of cognition remains ambiguous and future research is needed to fully establish the most appropriate methodology to establish whether deficits exists within a sample. Despite these difficulties this thesis has attempted to consider a number of different approaches of executive function even when accounting for data collection in a non-clinical community setting.

There are a number of problems with cognitive tests and the use of programmes to tap into targeted areas and this results in questioning the validity of using them. Cognitive tests have been said to be 'crude and unspecified' (p. 201) in that the processes that they are meant to be engaged with may not be sensitive enough to distinguish executive function in clinical settings (Chan et al., 2008). This would also be expected in a community setting. Similar tests are used to measure a range of cognitive functions and the interchangeable terminology and large number of concepts causes problems for researchers. Miyake et al.'s (2000) conception of executive function is paradigmatic and it has been suggested that modifications may need to be made to account for these variances. Their work provides an overview of executive function but is not definitive. They claim that their model may not be a complete work and that some functions may be missing.

Morra et al. (2017) discussed this work and argued that inhibition may be a set of functions within itself that can impact the other elements rather than a unitary function. Inhibition can be associated with shifting where previous mental sets are inhibited and updating where information which is no longer required is inhibited. The recognition of this was acknowledged by Miyake and Friedman (2012) and should be taken into account. Further to this there are a number of terms which are used interchangeably but should potentially be identified and measured individually, such as working memory and updating and shifting and cognitive flexibility. Morra et al. (2017) details that conceptual problems may arise if these constructs are not clarified appropriately. There is a lack of clarity on which psychological variables are being measured and it is common that some tasks will be seen to account for a number of concepts and researchers should be more transparent when choosing and reporting on these tasks.

The work of Miyake et al. (2000) has also been used to guide the tests which were considered and ultimately chosen for the cognitive test battery. It continues to be beneficial to have included these tests as the performance-based methods as it provides the thesis with a much needed framework in relation to the subject of executive function. However, it may have been beneficial to include common cognitive tests for better comparison purposes. A task such as the Stroop Task (Stroop, 1935) is regularly used to account for executive function and this is reflected in the systematic review (Chapter 3 p. 40). The Local-Global Task (Navon, 1977), Random Number Generator (adapted from Towse and Valentine, 1997) and Keep-Track Task (adapted from Yntema, 1963) are not as well used in weight-based research and this been difficult when assessing the executive functions used in this study against those identified in previous literature as there are not direct comparisons. The tasks which were utilised were well researched and considered in relation to their use within the studies. However, in hindsight it would have been advantageous to have selected corresponding cognitive tests to those contained within the systematic review. This should be a consideration for future research and especially within those populations where a longer test battery could allow for more popular cognitive tasks and which could provide additional outcome data which would be useful for weight research, for interventions and weight loss programmes.

A real consideration was made to choose appropriate tests to represent executive function in a non-clinical setting. An element of this was to choose tasks based upon time, choosing tasks which were short or could be shortened appropriately. The cognitive test battery used in this thesis is shorter than the average with some cognitive test batteries incorporating executive functions taking over an hour. Shorter test batteries such as the

Cambridge Neuropsychological Test Automated Battery (CANTAB) have been used extensively in global pharmaceutical trials and academic research and show high sensitivity across healthy and patient populations (Cambridge Cognition, 2019). However, it has been established that shorter cognitive tests may not provide a full assessment of human cognition. Brown et al. (2015) looked at the efficacy of short cognitive tests to identify dementia and concluded that although these shorter tests could identify deficits they could not provide a diagnosis. The work in this thesis aimed to identify deficits, not diagnose, so shorter tests are appropriate especially given the constraints of time. In the future, it may be important to consider what the use of longer tests or more comprehensive cognitive tests battery might have added.

Finally, how the studies were carried out in the field may have been problematic. Participants were aware that they were partaking in a weight related study but in terms of the self-report demographics and clinical factors, it may be that some have felt embarrassed or have not seen the need to be truthful when this has explored their personal life, especially in the self-report methodology used in Study Two. Within the business sample conversations regarding employee participation were explored with management and actively promoted by them via word of mouth. If this was to be repeated it would be beneficial to establish that the research and the employer were separate. To make it clear that no information would be shared with employers it would be useful to include as an additional point via email and documentation when recruiting and consenting these participants.

6.5. Future implications of the findings

Future work is required to explain the variability in the findings relating to the links between obesity and executive function, which are complex. A more defined view of executive function may provide answers. This could be achieved by looking at each of the functions individually and assessing participants on a battery of tests, aimed at clarifying the different aspects of each executive function, for example, inhibition (e.g. behavioural, motor, etc). This is in line with Miyake et al.'s (2000) approach, where they extract a latent variable 'inhibition' rather than focusing on individual tasks. This would potentially allow for a more fine-grained understanding of how weight influences executive function.

The findings from each study have implications for academics and clinicians. From an academic stance an understanding that there are alternatives to performance-based cognitive tests should be considered. Within the world of cognitive psychology there will always be a movement towards utilising this type of specific task to provide information of deficits, advantages and diagnoses. As touched upon in Chapter 2, tasks of executive function have been developed over a number of years, however the wealth of information which can be gleaned from some self-report measures may add a real-world understanding which also allows for quantitative analysis and to allow researchers to reflect and focus on how an individual is impacted.

Additionally, it has been suggested that highlighting poor cognitive function via performance based tests has the potential to act as the first step in highlighting potential incident dementia (Darweesh et al., 2017; Brenowitz et al., 2020). Therefore, these studies which have measured an obese population acts as the continued preliminary work to establish this. Moving forward this accumulation of work could be best seen through a longitudinal lens. Long-term research studies can often be difficult to set up and track but this is the time to follow up and continue the collection of data from community working age samples. If we are to see true associations between weight and other health variables in relation to dementia it is important to establish a pathway which can be followed.

In addition to this, future research should also control and account for as many potential confounds as possible. The crossover of health and cognitive psychology creates an additional layer of potential discrepancy. Cognitive test performance is known to be affected by number of variables including but not limited to age and gender, and it is difficult to simply pinpoint weight as an independent reason why a deficit is seen. In previous research reflected within the systematic review, variables such as depression were not accounted for and are known associators, controlling for this has presented a clearer picture. Rumination may also be a sensible inclusion as it could be an influencer of depressive symptoms. This is similar when measuring for weight, a number of health variables are often seen as a contributor or predictor of obesity. This can include, cardiovascular disease, diabetes, high blood pressure. Other individual difference factors that might account for the variability in findings include dieting status and restraint. It is important not only to collect as much detail as possible in this area but also to account for this statistically.

Some potential influencers have been considered across different aspects of the sample. Interestingly only a small number in each of the study samples self-reported that they had comorbidities such as diabetes, asthma, high blood pressure or heart disease which as presented in Chapter 1 has known effects on cognitive function and has the potential to affect test performance. According to the Health Survey for England 2019 (Public Heath England, 2019), in an adult population 7.1% have been diagnosed by a doctor with diabetes and 10% of adults are being successfully treated for high blood pressure in the UK. Both samples, in Study One and Study Two, do not reflect these statistics and because of this have not been able to provide additional information about their influence. This is also reflected in the data which was collected for depression symptoms, with only a small number within the samples being above the threshold which represents clinically significant depression and would lead to a clinical referral. Mental Health First Aid England statistics show 24% of women and 13% of men in England are diagnosed with depression in their lifetime (2020). It has to be considered that participants may not have wanted to disclose their medical information or were unaware of any potential problems. Within this study these areas of interest as discussed above have not had a significant influence on weight or cognitive performance.

6.6. Conclusion

Overall, this thesis has provided an insight into the relationship between weight and executive function. A systematic review provided the foundation for empirical work, highlighting the potential need to explore all three executive functions based on Miyake et al.'s (2000) model. All six WHO BMI weight categories, recruitment to a community population and the incorporation of both self-report and performance-based measures were all explored.

Performance-based cognitive tests were utilised to distinguish if an individual had a cognitive advantage or disadvantage based upon their weight group classification. The outcomes were ambiguous, but differences were seen even in a limited capacity across the studies with tasks of updating and shifting being most prominent in the upper obese categories. Obese and underweight categories, which had previous been explored individually were found to exhibit similar results in the first study but failed to replicate these in the second study. It would be beneficial to further understand why these inconsistencies may have occurred. An introduction of additional measures would be beneficial. If this research was to be repeated, the inclusion of measures of eating disorder or eating behaviour questionnaires would be useful to gain a better understanding of the sample. Consideration of other potential explanations for the differences between the studies including rumination and dietary restraint are factors which can be measured in a community population is required.

Empirical work also examined the association between performance-based and self-report methodologies. It could not be established that the executive function deficits observed via the cognitive tests are mirrored by deficits using the self-report method, which would potentially highlight the real-world impact of being disadvantaged by an executive function deficit. There is scope to examine if self-report and cognitive tasks are measuring different constructs and the impact of different measures of weight on cognitive decline. Further to this, it would be beneficial to get a better understanding of which cognitive tasks are most sensitive in a community population.

Much of the work which has been discussed in this thesis has come from cross-sectional studies which provides a snapshot view of a community population, but future studies may consider a longitudinal view. This would allow research to determine variable patterns over time. With the addition of the measurements discussed above, a longitudinal approach may account for the inconsistencies which were seen in the thesis. One of the key advantages of this work is the large participant numbers which were recruited and if replicated would be beneficial to a longitudinal sample.

Overall, the systematic review and empirical work shows that the link between weight and executive function is complex, some studies have highlighted deficits whilst others have not. The emphasis now needs to be on trying to understand the reasons for these inconsistent effects and the potential mechanisms which drive these differences.

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Appendix 1 – PSYSOC Ethics Committee Approval

27th April 2015

Janice Abbott/Montana Tiffaine Mullen
School of Psychology
University of Central Lancashire

Dear Janice/Montana,

Re: PSYSOC Ethics Committee Application
Unique Reference Number: PSYSOC 199

The PSYSOC ethics committee has granted approval of your proposal application '**The Influence of Body Size on Memory**'. Approval is granted up to the end of project date* or for 5 years from the date of this letter, whichever is the longer. It is your responsibility to ensure that

- the project is carried out in line with the information provided in the forms you have submitted
- you regularly re-consider the ethical issues that may be raised in generating and analysing your data
- any proposed amendments/changes to the project are raised with, and approved, by Committee
- you notify roffice@uclan.ac.uk if the end date changes or the project does not start
- serious adverse events that occur from the project are reported to Committee
- a closure report is submitted to complete the ethics governance procedures (Existing paperwork can be used for this purposes e.g. funder's end of grant report; abstract for student award or NRES final report. If none of these are available use e-Ethics Closure Report Proforma).

Yours sincerely,

Cath Larkins
Deputy Vice-Chair
PSYSOC Ethics Committee

Appendix 2 – Demographic and Clinical Data Sheet

Demographic and Clinical Data Sheet

The Influence of Body Size on Memory

DATE...

PARTICIPANT NUMBER………………………………………………………….

RECRUITMENT COMMUNITY CENTRE/BUSINESS/UCLAN

AGE...

MALE/FEMALE..

EMPLOYMENT STATUS………………………… POSTCODE…………………….

HEIGHT.................. WEIGHT....................

BMI...

Chronic Conditions

HIGH BLOOD PRESSURE	Y/N
HIGH CHOLESTEROL	Y/N
DIABETES	Y/N
HEART DISEASE	Y/N
ASTHMA/LUNG DISEASE	Y/N
STROKE	Y/N

OTHER………………………………………………………………….

Appendix 3 – Centre for Epidemiologic Studies – Depression Scale

CENTER FOR EPIDEMIOLOGIC STUDIES—DEPRESSION SCALE
Circle the number of each statement which best describes how often you felt or behaved this way – DURING THE PAST WEEK.

	Rarely or none of the time (less than 1 day)	**Some or a little of the time (1-2 days)**	**Occasionally or a moderate amount of the time (3-4 days)**	**Most or all of the time (5-7 days)**
During the past week:				
1. I was bothered by things that usually don't bother me	0	1	2	3
2. I did not feel like eating; my appetite was poor	0	1	2	3
3. I felt that I could not shake off the blues even with help from my family and friends	0	1	2	3
4. I felt that I was just as good as other people	0	1	2	3
5. I had trouble keeping my mind on what I was doing	0	1	2	3
6. I felt depressed	0	1	2	3
7. I felt that everything I did was an effort	0	1	2	3
8. I felt hopeful about the future	0	1	2	3
9. I thought my life had been a failure	0	1	2	3
10. I felt fearful	0	1	2	3
11. My sleep was restless	0	1	2	3
12. I was happy	0	1	2	3
13. I talked less than usual	0	1	2	3
14. I felt lonely	0	1	2	3
15. People were unfriendly	0	1	2	3
16. I enjoyed life	0	1	2	3
17. I had crying spells	0	1	2	3
18. I felt sad	0	1	2	3

19. I felt that people disliked me	0	1	2	3
20. I could not get “going”	0	1	2	3

Appendix 4 – Considerations of Performance-Based Assessments of Executive Function

Each of the Miyake et al's (2000) cognitive test battery tests were assessed, and considerations were made about the following:

Ease of programming – The choice of cognitive test had to fall in line with the computer software which was available and the researcher skill to programme the tests. The level of complexity for programming each of the tasks was assessed by the researcher and included whether or not the cognitive test programming could be completed using the software design available to the researcher. The time taken to complete the programming of the cognitive test had to be considered and had to account for not only individual cognitive test but the overall time which would have to be taken to programme all four separate tests.

Testing time length – With a 25 minutes completion time for the full cognitive battery, each cognitive test was allotted a 6 minute time slot. Each of the prospective cognitive tasks were assessed for the time taken to complete the test based upon the minimum number of trials or the reduced amount of blocks which could be completed. The testing time also had to incorporate the asking of pre-test questions, the practice block/trial, the main trial and post-test questions.

Equipment requirement – The equipment required to complete the task had to be limited. As the tasks were to be completed in the community setting and the researcher would have to carry and manoeuvre the equipment. There was the potential that the researcher would have to transport and move sites on the same day. With this is mind only essential equipment would be used with the ideal being that only a laptop plus paper tests would be required for the cognitive test battery.

Set up time – As highlighted in the above, there would be opportunities to capture participant data on the same day at different sites, set-up time was therefore an important consideration. At each of the sites, rooms were booked at specific times and to allow for the maximum amount of time to collect data the set-up of the tasks could not be extensive. This was in part determined by the set-up of the laptop plus any additional equipment, if any, for each of the tasks. For context, the overall research time was already reduced by 10 minutes for the set up of weight and height related equipment.

Test accuracy - In a non-laboratory setting, one of the cognitive battery features which can be controlled for the most are the tasks which require a computer. They are a reliable way to test and ensure a high probability that each participant will all have the same visual experience. This experimental method provides consistency in not only how participants view the tasks but also the precision of the timings throughout. It is important to provide a range of different type of tests but it is crucial that the accuracy of the dependent variable becomes a central consideration.

Test Stimuli - With the limited number of tests which could be used it was important to control and to have a range of stimuli which a participant is exposed to e.g. numerical, written, colour, sound. The type of stimuli provides a basis for cognitive tests and to account for participant preference or disadvantages the current research will use different types of stimuli across the four chosen tasks.

In the following sections each of the executive functions the tasks will be introduced, methodology explained, and the above considerations will be assessed with key findings highlighted. Finally, a chosen task will be outlined for each executive function.

Shifting Tasks

The plus/minus task (adapted from Jersild., 1927 and Spector and Biederman., 1976)

Method. The plus/minus task is a measure of shifting performance. The plus/minus task consists of three lists of 30, two-digit numbers and the participants are asked to complete each task related to each list. They included adding 3 to each number, to subtract 3 from the two-digit number and to alternatively add and subtract three from each two digit number in the list. A stopwatch is used to record the total time it takes for participants to complete each list.

Considerations. This is a pen and paper task which meant that this task did not have to be programmed nor was any computer equipment required. This test is relatively quick to set up and had the opportunity to utilise numerical stimuli. It had the potential to be a long task due to expected differences in individual sum ability which may have taken the task over the 6 minutes limit mark. This task requires a stopwatch to be used by the researcher to record the time taken by participants, a more simple task but would be better but when compared with other tasks there were some which could fully use the computer programme as the timing resource which would in turn increase accuracy.

The number/letter task (Adapted from Rogers & Monsell., 1995).

Method. The number/letter task is a measure of shifting performance. In this task, participants are presented with a number and letter pair (e.g. B3) in one of four quadrants on a computer screen. The target is to indicate if the letter is a vowel or a consonant or the number is odd or even dependent on where the number and letter is positioned in the four quadrants screen. There is a practice and main version of the task where the target moves and rotates between the four quadrants with some trials requiring switching whilst others do not.

Considerations. This cognitive test, completed using a laptop only, is a task which the researcher could have programmed using the programming suite which was available and would have required very little set-up. As discussed earlier, to avoid disadvantaging participants a range of different stimuli were chosen. However, the stimuli for this task combines numbers and letters stimuli which would be mirrored in alternative tasks. For this reason this task was not used.

Chosen Task - Local–global task (based on the Navon, 1977)

Method. The Local-Global task is a measure of shifting performance. A computerised version of this test was considered where a geometric figure the ‘global’ figure composed of much smaller, ‘local’ figures is presented on a computer screen. Participants are instructed to indicate either what the ‘global’ figure is or what the ‘local’ figures are as quickly as possible with response time being the key indicator of shift cost.

Considerations. This was one of the easier tasks to programme and could be completed within the 6 minute time limit, accounting for those who took an excessively long time to complete each trial. A task which only need the use of a laptop it was very easy to set up and required no additional equipment which would eat into research time. Overall this was a very feasible task, easy to complete and easy to set up and would provide accurate results based upon computer assessed response times. This was chosen as the most appropriate task to measure the shifting function.

Updating Tasks

Tone Monitoring (modified from the Mental Counters task developed by Larson, Merritt, & Williams, 1988),

Method. The tone monitoring task is a measure of updating performance. In the task participants are presented with four trial blocks, each block consisted of a series of 25 tones presented for 500 ms. Blocks included a mixed order of high-pitched tones (880 Hz), medium-pitched tones (440 Hz),low-pitched tones (220 Hz), and 1 tone randomly selected from the three pitches. The aim of the task is to respond when the 4th tone of each pitch was presented (e.g., after hearing the 4th high tone, the 4th medium tone, or the 4th low tone). This required participants to monitor and Keep-Track of the number of times each pitch had been presented.

Considerations. A timely task which would have been relatively simple to programme and would have been an opportunity to include audio stimuli. However, it was the set up and equipment considerations which raised concerns here. This task required additional audio equipment to ensure an optimum audio experience so that the differing pitched tones could be well defined. This created a problem when it came to the logistical plan for moving and setting up equipment across the sites. With limited time before and after participants were seen, it was important that set up could be completely swiftly with a minimum number of checks to allow for consistency. The amount of time to set up the equipment would have been considerable and it was also deemed inappropriate to include any further equipment as the sole researcher was already at capacity as to what could be comfortably carried across the sites.

Letter Memory (adapted from Morris & Jones, 1990)

Method. The letter memory task is a measure of updating performance. Several letters from a list were presented serially with the aim to recall the last 4 letters presented in the list. Participants were asked to say out loud the last 4 letters by adding the most recent letter and dropping the 5th letter back and then saying the new string of 4 letters out loud. For example, if the letters presented were ‘‘A, M, C, L, J, S, F,’’ the participants should have said, ‘‘A . . . AM . . . AMC . . . AMCL . . . MCLJ . . . CLJS . . . LJSF’’ and then recall ‘‘LJSF’’ at the end of the trial. Across the trials the number of letters presented were 5, 7, 9 or 11.

Considerations. As with the Tone Monitoring task this test required additional recording equipment to account for the number of letters which were correctly recalled which would have led to difficulties transporting and setting up the study. It was considered that the researcher could write down or mark off the answers as the participant read aloud but due to the complexity of the letter presentation it may have been difficult to keep up with the pace and would have questioned the test accuracy of this task.

Chosen Task - The Keep-Track task (adapted from Yntema, 1963)

Method. The Keep-Track task is a measure of updating performance. Participants are shown several target categories on a computer screen. Words from each of the possible categories are then in a random order. Participants are to remember the last word presented in each of the target categories and to write these down. For example, if the target categories were metals, relatives and countries, at the end of the trial, participants recalled the last metal, the last relative, and the last country presented in the list. Participants performed three trials with four target categories and three trials with five target categories.

Considerations. This task was the easiest of all the tasks to be programmed as it included word stimuli only to be presented on the screen with an easy set up process. This task could also be completed with a 6 minute time limit, accounting for those participants who took a longer than expected time to recall the target word. This task also introduced a 'word' stimuli which is an alternative from the letter and number exemplars which are regularly used. This task required the use of a pen and paper but the task required only a small number of target category trials to be completed. The additional paperwork was not seen as a disadvantage as it did not impact what was already required for consenting and questionnaires. This was chosen as the most appropriate task to measure the updating function.

Inhibition Tasks

Antisaccade task (adapted from Roberts, Hager, & Heron, 1994)

Method. The antisaccade task is a measure of inhibition performance. The trial in this task began with a fixation point in the middle of the computer screen followed by the presentation of a initial cue and then the target 'arrow' stimulus. The participants were asked to indicate the direction of the arrow, made difficult by the requirement to inhibit the location of the initial cue. The cues and targets were both presented 3.4 inches away from the fixation point and participants were seated 18 inches from the computer monitor.

Considerations. This task has a very complex set-up. There is a precision element for this study which lies with the angles of the stimuli. This level of accuracy would not have been feasible in non-laboratory setting where it would be very difficult to control and set up for the precision that this task required for each participant. It would have been possible to complete this task but not in an appropriate time which meant it was discounted as a final task in the cognitive test battery.

Stop-signal task (based on Logan, 1994)

Method. The stop-signal task is a measure of inhibition performance. An initial block of trials is presented to build up a prepotent categorisation response where participants are presented with a word and instructed to categorise each as either an animal or non-animal as quickly as possible without making mistakes. In a second block of trials participants are instructed to continue performing as they had before but to not respond to those 'stop' trials where a computer-emitted tone could be heard. Participants are asked not to slow down in anticipation for the tones and are reminded to continue to respond as quickly as possible by the researcher / experimenter.

Considerations. Compared with other tasks this test required a longer testing time and this was to establish a certain type of response. The results are dependent on this established response and therefore a large number of trials within the initial block are required. Outside of a laboratory for this research it was not an option and would not have provided analysable results if the number of trials were reduced. The stop-signal task was not deemed an appropriate test.

Chosen Task - Stroop task (Stroop, 1935)

Method. The Stroop task is a measure of inhibition performance. In a computerised version of this task, participants are tasked with choosing the correct colour of a stimulus as quickly as possible. The task includes many trials where participants are required to report either the colour of the ink in which a word is printed or the name of the colour the word represents.

Considerations. This task could be easily programmed by the research and utilised a laptop only. This task required the addition of coloured keys to provide responses which has been pre-installed so did not add to the overall set-up time. This was a timely task and accounting for prolonged response times by participant this fell within the six-minute time limit. An additional reflection was the usefulness of this task in comparison to other studies of executive function. The Stroop task is a common task and implemented regularly in research looking into executive function and it will be easier to highlight, find norms and provide details on how the participants performed in comparison to other studies. This was chosen as the most appropriate task to measure the inhibition function.

Complex Tasks

The Wisconsin Card Sorting Task (Heaton, 1981; Kimberg, D'Esposito, and Farah, 1997)

Method. The WCST is a measure of complex executive function performance. A card or computerised version of this task where a deck of cards are presented depicting different numbers, different shapes and different colour. The task is to sort the cards according to one of three rules (i.e., numbers, shapes or colours). Participants are not aware of the rule and through trial and error, by receiving feedback after every sort, they must figure out the sorting rule. Participants must continue to sort in line with this rule but are aware that the rule will change, and again participants must shift their attention and sort the cards according to the new rule.

Considerations. The Wisconsin Card Sorting Task is a well-used test which could be used comparatively with other studies which could be programmed adequately. However, in a non-laboratory setting there are too many unknowns. The algorithm for this task is dependent on how quickly a participant can figure out and correctly identify each of the rules. The problem lies with those participants who may struggle over an extended period to get through a suitable number of trials to provide valid results within the 6 minute time limit. With the potential for null results those who were disadvantaged by the task may be excluded from the final analysis or difficulties may have arisen with comparing results. This task was discounted for this reason.

Tower of Hanoi.

Method. The Tower of Hanoi is a measure of complex executive function performance. This task can either be apparatus or computer-driven. Participants are required to get to an end configuration of four disks of varying size positioned on three pegs from a different starting configuration by moving the disks along the pegs. Participants are asked to do this as quickly as possible and in the fewest moves. A set of rules has to be followed to complete the task, these included that only one disk can be moved at a time, each disk must be placed on one of the pegs, and a larger disk can never be placed on top of a smaller disk.

Considerations. This task was easy to programmes and set up but as with the above task the testing time could not be controlled for. The task is based upon the completion of a puzzle and was dependent on the ability of the participant with some taking much longer than others to solve the task. Unlike other tasks where optional answers are provided, this task required a trial and error method until the task is completed. This is then replicated a number of times across different trials. With only a six minute time limit to complete the trials this was not a feasible task for the cognitive test battery.

Operation span task (adapted from Turner & Engle, 1989)

Method. The operation span task is a measure of complex executive function performance. A computerised task where participants receive a set of equation–word pairs on the screen. For each pair, participants are asked to read aloud and verify (true or false) a simple math equation (e.g., for $(3 * 4) – 6 = 5$) and following this were then asked to read aloud a single presented word (e.g., ‘‘queen’’). At the end of the trial, participants were required to recall all of the words from the entire set of equation–word pairs during the block. The only rule in place was that last pair presented should not be recalled first. After practicing on three trials with two equation–word pairs, participants then performed four target trials with three, four and five equation–word pairs.

Considerations. This task compared to the other tasks for all of the functions was one of the more complex. It is an easy task to programme and the test time length was adequate. However, it required additional audio equipment to capture each of the trials which would have been cumbersome to carry across the different research sites and without this the accuracy of the tests could be jeopardised. This task also utilises numerous different stimuli types whilst preferable the tasks in the cognitive test battery would only use a singular stimuli type per task.

Dual task (developed by Ekstrom, French, Harman, & Dermen, 1976)

Method. The dual task is a measure of complex executive function performance. A pen and paper task where participants complete three tasks. The first is to complete as many mazes as possible in a three minute period with set rules to avoid retracing lines or removing the pencil from the paper. In the second task participants complete a word generation task for three minutes. Letters are auditorily presented every twenty seconds and participants are asked to generate as many words as they can beginning with that letter. In the third and final task condition, participants performed the maze and word generation tasks simultaneously for three minutes.

Considerations. This task is a pen and paper test with no computer involvement. A preference is made for tasks which include computer-based programming where there is control over timings and therefore accuracy. This task is easy to set up but the three required tasks are to be completed in nine minutes and would not have been appropriate for this community based study. For this reason, this task was not included in the current research cognitive battery.

Chosen Task - Random Number Generator (Towse and Neil, 1998).

Method. The Random Number Generator is a measure of complex executive function performance. In this task participants hear computer-generated beeps. They are asked to say aloud a number from 1 to 9 to coincide with each beep. They are asked to pick numbers in as random an order as possible. Participants received a brief practice period and valid responses generated during an additional trial.

Considerations. This was a task which needed limited set up, could be completed within the time limit, was an easy task to programme and simple for participants to understand. The complex tasks were the last to be selected and this task introduced a numerical stimulus which was not yet represented by the others tasks. It was right to use additional stimuli such as an auditory cue and a simple 'beep' run through a programme was achievable in a non-laboratory setting. Further to this, no additional audio equipment would be needed to accomplish this as the speakers through the laptop would be enough to carry the simple 'beep' cue. This was chosen as the most appropriate task to measure executive function using a complex task.

Appendix 5 - Unadjusted quantile regressions of the lower quartile for the four cognitive measures for Study One.

	Total n=315					Males only n=142					Females only n=173				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	6.50	0.16	6.19	6.81	0.000	6.50	0.19	6.12	6.88	0.000	7.25	0.22	6.82	7.68	0.000
Underweight	0.50	0.31	-0.10	1.10	0.104	0.75	0.41	-0.06	1.56	0.068	-0.25	0.40	-1.03	0.53	0.529
Overweight	0.00	0.27	-0.53	0.53	1.000	0.18	0.32	-0.46	0.82	0.577	-1.00	0.38	-1.74	-0.26	0.009
Obese Class I	-0.25	0.28	-0.79	0.29	0.364	-0.50	0.38	-1.25	0.25	0.191	-1.00	0.35	-1.69	-0.31	0.005
Obese Class II	0.00	0.34	-0.68	0.68	1.000	0.00	0.42	-0.83	0.83	1.000	-1.25	0.47	-2.18	-0.32	0.009
Obese Class III	0.00	0.35	-0.68	0.68	1.000	-0.75	0.46	-1.66	0.16	0.107	-0.75	0.45	-1.64	0.14	0.097
Local-Global Difference															
Intercept	-46.67	64.70	-173.99	80.65	0.471	-143.91	116.03	-373.37	85.55	0.217	19.12	87.70	-154.04	192.28	0.828
Underweight	223.50	125.19	-22.84	469.84	0.075	320.74	248.86	-171.40	812.88	0.200	215.77	157.09	-94.39	525.93	0.171
Overweight	-106.04	110.39	-323.26	111.18	0.338	29.91	196.30	-358.29	418.11	0.879	-312.89	150.96	-610.96	-14.83	0.040
Obese Class I	-33.95	112.42	-255.17	187.27	0.763	100.57	232.07	-358.36	559.50	0.665	-193.48	139.06	-468.05	81.09	0.166
Obese Class II	10.50	138.27	-261.58	282.58	0.940	184.23	248.86	-307.91	676.37	0.460	-173.25	186.73	-541.94	195.44	0.355
Obese Class III	246.49	142.07	-33.07	526.05	0.084	10.91	282.06	-546.88	568.70	0.969	381.50	177.96	30.12	732.88	0.034
Stroop Difference															
Intercept	-57.32	52.97	-161.55	46.91	0.280	40.01	71.34	-101.07	181.09	0.576	-143.27	69.65	-280.78	-5.76	0.041
Underweight	123.92	102.84	-78.43	326.27	0.229	-7.68	153.00	-310.26	294.90	0.960	217.86	125.56	-30.05	465.77	0.085
Overweight	61.82	90.12	-115.51	239.15	0.493	0.29	120.69	-238.38	238.96	0.998	142.20	119.19	-93.13	377.53	0.235
Obese Class I	57.36	92.32	-124.30	239.02	0.535	-19.56	142.68	-301.71	262.59	0.891	1.89	111.07	-217.40	221.18	0.986
Obese Class II	-80.12	113.61	-303.67	143.43	0.481	-35.97	153.00	-338.55	266.61	0.814	-165.58	149.38	-460.52	129.36	0.269
Obese Class III	221.86	118.44	-11.20	454.92	0.062	128.64	173.41	-214.30	471.58	0.459	307.81	145.68	20.18	595.44	0.036
Keep-Track															
Intercept	7.00	0.47	6.07	7.93	0.000	8.00	0.57	6.87	9.13	0.000	6.00	0.79	6.00	0.79	0.000
Underweight	-4.00	0.92	-5.81	-2.19	0.000	-4.00	1.23	-6.42	-1.58	0.001	-4.00	1.43	-4.00	1.43	0.006
Overweight	1.00	0.81	-0.59	2.59	0.216	1.00	0.97	-0.91	2.91	0.303	2.00	1.36	2.00	1.36	0.142
Obese Class I	1.00	0.83	-0.63	2.63	0.227	-1.00	1.14	-3.26	1.26	0.383	2.00	1.26	2.00	1.26	0.115
Obese Class II	0.00	1.02	-2.00	2.00	1.000	-5.00	1.23	-7.42	-2.58	0.000	1.00	1.70	1.00	1.70	0.557
Obese Class III	-2.00	1.04	-4.06	0.06	0.056	-3.00	1.39	-5.75	-0.25	0.033	-1.00	1.62	-1.00	1.62	0.538

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Appendix 6 - Unadjusted quantile regressions of the median for the four cognitive measures for Study One

	Total n=315					Males only n=142					Females only n=173				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	7.75	0.15	7.46	8.04	0.000	7.25	0.21	6.83	7.67	0.000	8.00	0.20	7.61	8.40	0.000
Underweight	0.27	0.28	-0.29	0.83	0.344	0.59	0.45	-0.31	1.49	0.197	0.15	0.36	-0.56	0.86	0.678
Overweight	-0.50	0.25	-0.99	-0.01	0.046	0.00	0.36	-0.71	0.71	1.000	-0.75	0.34	-1.43	-0.07	0.030
Obese Class I	-0.50	0.26	-1.00	0.00	0.051	-1.00	0.42	-1.84	-0.16	0.020	-0.55	0.32	-1.18	0.08	0.087
Obese Class II	0.00	0.32	-0.63	0.63	1.000	0.75	0.47	-0.17	1.67	0.111	-0.75	0.43	-1.60	0.10	0.083
Obese Class III	0.00	0.32	-0.64	0.64	1.000	0.50	0.52	-0.52	1.52	0.334	-0.89	0.41	-1.70	-0.08	0.031
Local-Global Difference															
Intercept	202.06	66.35	71.51	332.61	0.003	102.97	105.39	-105.45	311.39	0.330	281.73	113.04	58.54	504.92	0.014
Underweight	286.54	128.37	33.95	539.13	0.026	385.63	226.04	-61.38	832.64	0.090	481.81	202.47	82.04	881.59	0.018
Overweight	-71.72	113.19	-294.45	151.01	0.527	150.31	178.30	-202.29	502.91	0.401	-210.74	194.58	-594.92	173.44	0.280
Obese Class I	-69.67	115.27	-296.50	157.16	0.546	108.32	210.79	-308.52	525.16	0.608	-149.34	179.24	-503.24	204.56	0.406
Obese Class II	-70.01	141.78	-348.99	208.97	0.622	41.03	226.04	-405.98	488.04	0.856	-149.68	240.68	-624.89	325.53	0.535
Obese Class III	798.50	145.68	511.84	1085.16	0.000	474.42	256.20	-32.22	981.06	0.066	828.07	229.38	375.17	1280.97	0.000
Stroop Difference															
Intercept	264.48	62.80	140.90	388.06	0.000	291.10	91.50	110.16	472.04	0.002	93.39	90.69	-85.66	272.44	0.305
Underweight	199.22	121.93	-40.70	439.14	0.103	219.65	196.24	-168.42	607.72	0.265	339.60	163.49	16.81	662.39	0.039
Overweight	-131.45	106.85	-341.71	78.81	0.220	66.42	154.79	-239.69	372.53	0.669	-54.55	155.20	-360.96	251.86	0.726
Obese Class I	-107.07	109.46	-322.46	108.32	0.329	66.85	182.99	-295.03	428.73	0.715	59.76	144.62	-225.76	345.28	0.680
Obese Class II	-48.10	134.70	-313.15	216.95	0.721	-78.47	196.24	-466.54	309.60	0.690	122.99	194.51	-261.03	507.01	0.528
Obese Class III	535.78	140.43	259.45	812.11	0.000	271.70	222.42	-168.14	711.54	0.224	760.61	189.69	386.10	1135.12	0.000
Keep-Track															
Intercept	9.00	0.59	7.85	10.16	0.000	10.00	0.71	8.60	11.40	0.000	9.00	0.74	7.55	10.45	0.000
Underweight	0.00	1.14	-2.24	2.24	1.000	-1.00	1.52	-4.00	2.00	0.511	0.00	1.33	-2.62	2.62	1.000
Overweight	1.00	1.00	-0.96	2.96	0.317	1.00	1.20	-1.37	3.37	0.405	1.00	1.26	-1.49	3.49	0.428
Obese Class I	1.00	1.02	-1.01	3.01	0.329	0.00	1.42	-2.80	2.80	1.000	2.00	1.17	-0.32	4.32	0.090
Obese Class II	1.00	1.26	-1.48	3.48	0.427	-1.00	1.52	-4.00	2.00	0.511	1.00	1.58	-2.12	4.12	0.527
Obese Class III	-2.00	1.29	-4.55	0.55	0.123	-4.00	1.72	-7.40	-0.60	0.022	1.00	1.50	-1.97	3.97	0.507

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Appendix 7 - Unadjusted quantile regressions of the upper quartile for the four cognitive measures for Study One.

	Total n=315					Males only n=142					Females only n=173				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	8.25	0.04	8.17	8.33	0.000	8.25	0.10	8.06	8.44	0.000	8.15	0.08	8.15	0.08	0.000
Underweight	0.00	0.08	-0.15	0.15	1.000	0.00	0.20	-0.40	0.40	1.000	0.10	0.14	0.10	0.14	0.474
Overweight	-0.10	0.07	-0.23	0.03	0.137	-0.10	0.16	-0.42	0.22	0.535	0.10	0.13	0.10	0.13	0.451
Obese Class I	0.00	0.07	-0.14	0.14	1.000	0.00	0.19	-0.38	0.38	1.000	0.10	0.12	0.10	0.12	0.418
Obese Class II	-0.10	0.09	-0.27	0.07	0.245	-0.10	0.21	-0.51	0.31	0.634	0.29	0.17	0.29	0.17	0.082
Obese Class III	0.00	0.09	-0.17	0.17	1.000	-0.10	0.23	-0.56	0.36	0.666	0.10	0.16	0.10	0.16	0.527
Local-Global Difference															
Intercept	632.78	119.69	397.25	868.31	0.000	428.02	133.12	164.77	691.27	0.002	700.71	143.31	417.76	983.66	0.000
Underweight	433.92	231.59	-21.78	889.62	0.062	355.84	285.50	208.76	920.44	0.215	874.69	256.69	367.87	1381.51	0.001
Overweight	77.18	204.21	324.65	479.01	0.706	360.79	225.20	-84.56	806.14	0.111	-49.11	246.68	536.17	437.95	0.842
Obese Class I	77.68	207.97	331.54	486.90	0.709	454.07	266.23	-72.42	980.56	0.090	-71.01	227.24	519.68	377.66	0.755
Obese Class II	-55.85	255.78	559.16	447.46	0.827	256.91	285.50	307.69	821.51	0.370	-440.80	305.13	1043.25	161.65	0.150
Obese Class III	911.05	262.82	393.89	1428.21	0.001	700.48	323.59	60.56	1340.40	0.032	1157.13	290.80	582.96	1731.30	0.000
Stroop Difference															
Intercept	598.65	119.03	364.44	832.86	0.000	667.89	144.34	382.44	953.34	0.000	582.84	174.04	239.22	926.46	0.001
Underweight	301.62	231.09	153.09	756.33	0.193	298.84	309.58	313.37	911.05	0.336	288.42	313.75	331.04	907.88	0.359
Overweight	-172.05	202.51	570.53	226.43	0.396	-40.62	244.19	523.53	442.29	0.868	-335.80	297.83	923.83	252.23	0.261
Obese Class I	68.94	207.45	339.27	477.15	0.740	73.45	288.68	497.44	644.34	0.800	66.96	277.53	480.98	614.90	0.810
Obese Class II	112.44	255.29	389.88	614.76	0.660	-127.40	309.58	739.61	484.81	0.681	414.73	373.27	322.24	1151.70	0.268
Obese Class III	1001.08	266.15	477.37	1524.79	0.000	1306.45	350.88	612.57	2000.33	0.000	1016.89	364.03	298.17	1735.61	0.006
Keep-Track															
Intercept	13.00	0.47	12.07	13.93	0.000	13.00	0.76	11.49	14.51	0.000	12.00	0.79	10.44	13.57	0.000
Underweight	-1.00	0.92	-2.81	0.81	0.278	-1.00	1.63	-4.23	2.23	0.542	-1.00	1.43	-3.82	1.82	0.485
Overweight	1.00	0.81	-0.59	2.59	0.216	1.00	1.29	-1.55	3.55	0.439	2.00	1.36	-0.68	4.68	0.142
Obese Class I	0.00	0.83	-1.63	1.63	1.000	0.00	1.52	-3.01	3.01	1.000	1.00	1.26	-1.50	3.50	0.430
Obese Class II	-1.00	1.02	-3.00	1.00	0.326	-1.00	1.63	-4.23	2.23	0.542	0.00	1.70	-3.36	3.36	1.000
Obese Class III	-1.00	1.04	-3.06	1.06	0.339	-3.00	1.85	-6.66	0.66	0.108	0.00	1.62	-3.20	3.20	1.000

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Appendix 8 – Personal Health Questionnaire Depression Scale (PHQ-8)

Personal Health Questionnaire Depression Scale (PHQ-8)
Over the **last 2 weeks**, how often have you been bothered by any of the following problems? (circle **one** number on each line)

	Not at all	**Several days**	**More than half the days**	**Nearly every day**
1. Little interest or pleasure in doing things	0	1	2	3
2. Feeling down, depressed, or hopeless	0	1	2	3
3. Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4. Feeling tired or having little energy	0	1	2	3
5. Poor appetite or overeating	0	1	2	3
6. Feeling bad about yourself — or that you are a failure or have let yourself or your family down	0	1	2	3
7. Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8. Moving or speaking so slowly that other people could have noticed? Or the opposite — being so fidgety or restless that you have been moving .around a lot more than usual	0	1	2	3

Appendix 9 – Pittsburgh Sleep Quality Index

PITTSBURGH SLEEP QUALITY INDEX – SLEEP QUESTIONNAIRE

Instructions: The following questions relate to your **usual sleep habits** during the **past month only**. Your answers should indicate the most accurate reply for the **majority of days and nights** in the past month. Please answer all questions.

During the past month,

1. When have you usually gone to bed? _________
2. How long (in minutes) has it taken you to fall asleep each night? _________
3. When have you usually gotten up in the morning? _________
4. How many hours of actual sleep do you get at night? (This may be different than the number of hours you spend in bed) _________

Please tick the appropriate box below

5. During the past month, how often have you had trouble sleeping because you	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
a. Cannot get to sleep within 30 minutes				
b. Wake up in the middle of the night or early morning				
c. Have to get up to use the bathroom				
d. Cannot breathe comfortably				
e. Cough or snore loudly				
f. Feel too cold				
g. Feel too hot				
h. Have bad dreams				
i. Have pain				
j. Other reason(s), please describe, including how often you have had trouble sleeping because of this reason(s):				
6. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				

7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?

	Very good	Fairly good	Fairly bad	Very bad
9. During the past month, how would you rate your sleep quality over all?				

Appendix 10 – The Behavior Rating Inventory of Executive Function – Adults Version (BRIEF-A)

Your Name ______________________ Today's Date ___/___/___

Gender ☐ Male ☐ Female Age ________ Date of Birth ___/___/___

Years of Education: ________ Level of Education: ☐ Less than High School ☐ High School ☐ College ☐ Master's degree ☐ Doctorate ☐ Other

During the past month, how often has each of the following behaviors been a *problem*?

N = Never S = Sometimes O = Often

1.	I have angry outbursts	N	S	O
2.	I make careless errors when completing tasks	N	S	O
3.	I am disorganized	N	S	O
4.	I have trouble concentrating on tasks (such as chores, reading, or work)	N	S	O
5.	I tap my fingers or bounce my legs	N	S	O
6.	I need to be reminded to begin a task even when I am willing	N	S	O
7.	I have a messy closet	N	S	O
8.	I have trouble changing from one activity or task to another	N	S	O
9.	I get overwhelmed by large tasks	N	S	O
10.	I forget my name	N	S	O
11.	I have trouble with jobs or tasks that have more than one step	N	S	O
12.	I overreact emotionally	N	S	O
13.	I don't notice when I cause others to feel bad or get mad until it is too late	N	S	O
14.	I have trouble getting ready for the day	N	S	O
15.	I have trouble prioritizing activities	N	S	O
16.	I have trouble sitting still	N	S	O
17.	I forget what I am doing in the middle of things	N	S	O
18.	I don't check my work for mistakes	N	S	O
19.	I have emotional outbursts for little reason	N	S	O
20.	I lie around the house a lot	N	S	O
21.	I start tasks (such as cooking, projects) without the right materials	N	S	O
22.	I have trouble accepting different ways to solve problems with work, friends, or tasks	N	S	O
23.	I talk at the wrong time	N	S	O
24.	I misjudge how difficult or easy tasks will be	N	S	O
25.	I have problems getting started on my own	N	S	O
26.	I have trouble staying on the same topic when talking	N	S	O
27.	I get tired	N	S	O
28.	I react more emotionally to situations than my friends	N	S	O
29.	I have problems waiting my turn	N	S	O
30.	People say that I am disorganized	N	S	O
31.	I lose things (such as keys, money, wallet, homework, etc.)	N	S	O
32.	I have trouble thinking of a different way to solve a problem when stuck	N	S	O
33.	I overreact to small problems	N	S	O
34.	I don't plan ahead for future activities	N	S	O
35.	I have a short attention span	N	S	O
36.	I make inappropriate sexual comments	N	S	O
37.	When people seem upset with me, I don't understand why	N	S	O
38.	I have trouble counting to three	N	S	O

During the past month, how often has each of the following behaviors been a *problem*?

N = Never S = Sometimes O = Often

39. I have unrealistic goals	N	S	O
40. I leave the bathroom a mess	N	S	O
41. I make careless mistakes	N	S	O
42. I get emotionally upset easily	N	S	O
43. I make decisions that get me into trouble (legally, financially, socially)	N	S	O
44. I am bothered by having to deal with changes	N	S	O
45. I have difficulty getting excited about things	N	S	O
46. I forget instructions easily	N	S	O
47. I have good ideas but cannot get them on paper	N	S	O
48. I make mistakes	N	S	O
49. I have trouble getting started on tasks	N	S	O
50. I say things without thinking	N	S	O
51. My anger is intense but ends quickly	N	S	O
52. I have trouble finishing tasks (such as chores, work)	N	S	O
53. I start things at the last minute (such as assignments, chores, tasks)	N	S	O
54. I have difficulty finishing a task on my own	N	S	O
55. People say that I am easily distracted	N	S	O
56. I have trouble remembering things, even for a few minutes (such as directions, phone numbers)	N	S	O
57. People say that I am too emotional	N	S	O
58. I rush through things	N	S	O
59. I get annoyed	N	S	O
60. I leave my room or home a mess	N	S	O
61. I get disturbed by unexpected changes in my daily routine	N	S	O
62. I have trouble coming up with ideas for what to do with my free time	N	S	O
63. I don't plan ahead for tasks	N	S	O
64. People say that I don't think before acting	N	S	O
65. I have trouble finding things in my room, closet, or desk	N	S	O
66. I have problems organizing activities	N	S	O
67. After having a problem, I don't get over it easily	N	S	O
68. I have trouble doing more than one thing at a time	N	S	O
69. My mood changes frequently	N	S	O
70. I don't think about consequences before doing something	N	S	O
71. I have trouble organizing work	N	S	O
72. I get upset quickly or easily over little things	N	S	O
73. I am impulsive	N	S	O
74. I don't pick up after myself	N	S	O
75. I have problems completing my work	N	S	O

Appendix 11 – UCLA Three-Item Loneliness Scale

UCLA THREE-ITEM LONELINESS SCALE
These questions are about how you feel about different aspects of your life. For each one, tell me how often you feel that way. (circle **<u>one</u>** number on each line)

	Hardly Ever	**Some of the Time**	**Often**
First, how often do you feel that you lack companionship: Hardly ever, some of the time, or often?	1	2	3
How often do you feel left out: Hardly ever, some of the time, or often?	1	2	3
How often do you feel isolated from others? (Is it hardly ever, some of the time, or often?)	1	2	3

Appendix 12 - Unadjusted quantile regressions of the lower quartile for the four cognitive measures for Study Two.

	Total n=400					Males only n=185					Females only n=214				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	6.00	0.14	5.72	6.28	0.000	6.00	0.20	5.61	6.39	0.000	6.00	0.21	5.58	6.42	0.000
Underweight	0.00	0.20	-0.39	0.39	1.000	0.00	0.27	-0.53	0.53	1.000	0.04	0.32	-0.58	0.66	0.899
Overweight	0.25	0.21	-0.17	0.67	0.245	0.25	0.29	-0.33	0.83	0.394	0.25	0.33	-0.41	0.91	0.453
Obese Class I	0.03	0.20	-0.37	0.43	0.882	0.25	0.29	-0.31	0.81	0.383	0.00	0.30	-0.60	0.60	1.000
Obese Class II	0.25	0.22	-0.19	0.69	0.260	0.28	0.30	-0.31	0.87	0.349	0.00	0.35	-0.69	0.69	1.000
Obese Class III	0.07	0.29	-0.50	0.64	0.811	0.07	0.41	-0.75	0.89	0.866	0.00	0.45	-0.89	0.89	1.000
Local-Global Difference															
Intercept	-463.28	124.37	-707.78	-218.78	0.000	-514.20	179.59	-868.58	-159.82	0.005	-152.00	153.94	-455.48	151.48	0.325
Underweight	-151.67	177.99	-501.59	198.25	0.395	-86.09	247.85	-575.18	403.00	0.729	-462.95	228.07	-912.58	-13.32	0.044
Overweight	109.77	190.18	-264.13	483.67	0.564	178.09	267.93	-350.61	706.79	0.507	-354.61	240.51	-828.77	119.55	0.142
Obese Class I	-21.08	179.11	-373.21	331.05	0.906	-52.47	261.34	-568.17	463.23	0.841	-285.62	220.00	-719.34	148.10	0.196
Obese Class II	-179.18	196.64	-565.78	207.42	0.363	-209.69	272.97	-748.34	328.96	0.443	-456.28	252.46	-953.98	41.42	0.072
Obese Class III	52.38	259.27	-457.35	562.11	0.840	-316.61	379.03	-1064.56	431.34	0.405	-179.66	326.55	-823.43	464.11	0.583
Stroop Difference															
Intercept	-470.97	115.53	-698.10	-243.84	0.000	-611.39	171.35	-949.52	-273.26	0.000	-328.13	125.88	-576.30	-79.96	0.010
Underweight	-37.80	165.34	-362.85	287.25	0.819	228.83	236.49	-237.84	695.50	0.335	-245.15	186.51	-612.84	122.54	0.190
Overweight	24.56	176.66	-322.76	371.88	0.890	186.03	255.64	-318.43	690.49	0.468	-124.83	196.68	-512.58	262.92	0.526
Obese Class I	98.47	166.38	-228.63	425.57	0.554	311.67	249.35	-180.38	803.72	0.213	-186.48	179.91	-541.16	168.20	0.301
Obese Class II	-36.77	182.66	-395.89	322.35	0.841	291.36	260.45	-222.59	805.31	0.265	-179.61	206.45	-586.61	227.39	0.385
Obese Class III	74.98	240.84	-398.52	548.48	0.756	-165.13	361.65	-878.78	548.52	0.649	102.33	267.04	-424.12	628.78	0.702
Keep-Track															
Intercept	8.00	0.55	6.91	9.09	0.000	7.00	0.72	5.58	8.42	0.000	8.00	0.87	6.29	9.71	0.000
Underweight	-1.00	0.79	-2.56	0.56	0.208	-1.00	0.99	-2.96	0.96	0.314	0.00	1.29	-2.54	2.54	1.000
Overweight	-1.00	0.85	-2.66	0.66	0.238	0.00	1.07	-2.11	2.11	1.000	0.00	1.36	-2.67	2.67	1.000
Obese Class I	-1.00	0.80	-2.57	0.57	0.211	1.00	1.05	-1.06	3.06	0.340	-2.00	1.24	-4.45	0.45	0.108
Obese Class II	-2.00	0.88	-3.72	-0.28	0.023	0.00	1.09	-2.15	2.15	1.000	-2.00	1.42	-4.81	0.81	0.162
Obese Class III	-2.00	1.15	-4.27	0.27	0.084	-1.00	1.52	-3.99	1.99	0.510	-2.00	1.84	-5.63	1.63	0.279

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Appendix 13 - Unadjusted quantile regressions of the median for the four cognitive measures for Study Two.

	Total n=400					Males only n=185					Females only n=214				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	6.75	0.14	6.47	7.03	0.000	6.64	0.22	6.20	7.08	0.000	6.91	0.20	6.53	7.29	0.000
Underweight	0.00	0.20	-0.40	0.40	1.000	0.13	0.31	-0.48	0.74	0.672	-0.16	0.29	-0.73	0.41	0.581
Overweight	0.25	0.22	-0.17	0.67	0.248	0.11	0.33	-0.54	0.76	0.741	0.10	0.30	-0.50	0.70	0.743
Obese Class I	0.00	0.20	-0.40	0.40	1.000	0.43	0.32	-0.21	1.07	0.186	-0.18	0.28	-0.73	0.37	0.519
Obese Class II	0.13	0.22	-0.31	0.57	0.561	0.12	0.34	-0.55	0.79	0.723	0.09	0.32	-0.54	0.72	0.779
Obese Class III	0.00	0.29	-0.58	0.58	1.000	-0.17	0.47	-1.10	0.76	0.718	0.34	0.41	-0.48	1.16	0.412
Local-Global Difference															
Intercept	11.04	99.79	-185.14	207.22	0.912	-202.29	158.17	-514.42	109.84	0.203	98.67	125.66	-149.07	346.41	0.433
Underweight	-126.59	142.81	-407.35	154.17	0.376	109.80	218.30	-320.98	540.58	0.616	-235.87	186.18	-602.92	131.18	0.207
Overweight	43.39	152.59	-256.61	343.39	0.776	141.07	235.98	-324.60	606.74	0.551	144.57	196.34	-242.51	531.65	0.462
Obese Class I	3.65	143.71	-278.88	286.18	0.980	222.73	230.18	-231.48	676.94	0.335	-175.45	179.60	-529.52	178.62	0.330
Obese Class II	-200.43	157.78	-510.62	109.76	0.205	12.90	240.42	-461.53	487.33	0.957	-286.19	206.09	-692.49	120.11	0.166
Obese Class III	29.44	208.03	-379.55	438.43	0.888	135.57	333.84	-523.20	794.34	0.685	102.96	266.58	-422.58	628.50	0.700
Stroop Difference															
Intercept	-30.50	89.17	-205.82	144.82	0.733	-126.98	134.14	-391.68	137.72	0.345	-13.15	128.67	-266.81	240.51	0.919
Underweight	94.03	127.62	-156.87	344.93	0.462	168.33	185.13	-196.99	533.65	0.364	134.80	190.63	-241.02	510.62	0.480
Overweight	7.11	136.36	-260.98	275.20	0.958	154.39	200.13	-240.52	549.30	0.441	-209.54	201.03	-605.87	186.79	0.298
Obese Class I	50.86	128.42	-201.62	303.34	0.692	111.08	195.20	-274.11	496.27	0.570	68.57	183.89	-293.96	431.10	0.710
Obese Class II	52.13	141.00	-225.07	329.33	0.712	209.51	203.89	-192.83	611.85	0.306	-88.55	211.02	-504.56	327.46	0.675
Obese Class III	120.00	185.90	-245.49	485.49	0.519	141.34	283.11	-417.33	700.01	0.618	255.20	272.95	-282.89	793.29	0.351
Keep-Track															
Intercept	9.00	0.27	8.46	9.54	0.000	9.00	0.53	7.95	10.05	0.000	9.00	0.48	8.05	9.95	0.000
Underweight	0.00	0.39	-0.77	0.77	1.000	0.00	0.74	-1.45	1.45	1.000	-1.00	0.72	-2.41	0.41	0.164
Overweight	0.00	0.42	-0.82	0.82	1.000	0.00	0.80	-1.57	1.57	1.000	0.00	0.76	-1.49	1.49	1.000
Obese Class I	0.00	0.40	-0.78	0.78	1.000	0.00	0.78	-1.53	1.53	1.000	0.00	0.69	-1.36	1.36	1.000
Obese Class II	-1.00	0.43	-1.85	-0.15	0.022	0.00	0.81	-1.60	1.60	1.000	-2.00	0.79	-3.56	-0.44	0.012
Obese Class III	-1.00	0.57	-2.12	0.12	0.081	0.00	1.13	-2.22	2.22	1.000	-2.00	1.03	-4.02	0.02	0.053

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.

Appendix 14 - Unadjusted quantile regressions of the upper quartile for the four cognitive measures for Study Two.

	Total n=400					Males only n=185					Females only n=214				
	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value	Est.*	SE	95% CI		p-value
Random Number Generator															
Intercept	7.53	0.17	7.19	7.87	0.000	7.58	0.23	7.14	8.02	0.000	7.43	0.25	6.95	7.91	0.000
Underweight	-0.02	0.25	-0.51	0.47	0.936	-0.07	0.31	-0.68	0.54	0.822	0.08	0.36	-0.64	0.80	0.826
Overweight	0.01	0.27	-0.51	0.53	0.970	-0.33	0.34	-0.99	0.33	0.327	0.32	0.38	-0.44	1.08	0.405
Obese Class I	0.17	0.25	-0.32	0.66	0.497	0.32	0.33	-0.33	0.97	0.330	-0.14	0.35	-0.83	0.55	0.690
Obese Class II	-0.13	0.27	-0.67	0.41	0.636	-0.33	0.34	-1.00	0.34	0.336	-0.03	0.40	-0.82	0.76	0.941
Obese Class III	-0.28	0.36	-0.99	0.43	0.439	-0.33	0.47	-1.27	0.61	0.488	-0.18	0.52	-1.21	0.85	0.730
Local-Global Difference															
Intercept	390.58	113.83	166.79	614.37	0.001	272.59	168.38	-59.68	604.86	0.107	475.32	112.43	253.68	696.96	0.000
Underweight	57.27	162.91	-263.01	377.55	0.725	268.51	232.39	-190.07	727.09	0.249	-133.88	166.57	-462.27	194.51	0.422
Overweight	218.56	174.07	-123.66	560.78	0.210	-4.11	251.22	-499.83	491.61	0.987	259.50	175.66	-86.80	605.80	0.141
Obese Class I	245.52	163.93	-76.78	567.82	0.135	531.44	245.04	47.91	1014.97	0.031	149.99	160.68	-166.78	466.76	0.352
Obese Class II	-169.10	179.98	-522.94	184.74	0.348	401.25	255.94	-103.80	906.30	0.119	-309.32	184.38	-672.82	54.18	0.095
Obese Class III	-92.58	237.31	-559.13	373.97	0.697	90.92	355.39	-610.37	792.21	0.798	-177.32	238.49	-647.50	292.86	0.458
Stroop Difference															
Intercept	469.55	110.64	252.02	687.08	0.000	370.39	169.20	36.51	704.27	0.030	562.66	131.05	304.31	821.01	0.000
Underweight	53.95	158.35	-257.37	365.27	0.734	-2.32	233.52	-463.12	458.48	0.992	41.10	194.16	-341.67	423.87	0.833
Overweight	-46.44	169.20	-379.08	286.20	0.784	-54.46	252.43	-552.59	443.67	0.829	-47.29	204.75	-450.94	356.36	0.818
Obese Class I	87.93	159.35	-225.35	401.21	0.581	235.33	246.22	-250.54	721.20	0.340	-130.07	187.29	-499.30	239.16	0.488
Obese Class II	-54.82	174.94	-398.76	289.12	0.754	153.97	257.18	-353.53	661.47	0.550	-469.99	214.92	-893.69	-46.29	0.030
Obese Class III	47.72	230.67	-405.77	501.21	0.836	-202.94	357.11	-907.63	501.75	0.571	70.33	277.99	-477.71	618.37	0.801
Keep-Track															
Intercept	11.00	0.37	10.27	11.73	0.000	11.00	0.72	9.58	12.42	0.000	11.00	0.43	10.14	11.86	0.000
Underweight	-1.00	0.53	-2.04	0.04	0.059	-1.00	0.99	-2.96	0.96	0.314	0.00	0.64	-1.27	1.27	1.000
Overweight	-2.00	0.56	-3.11	-0.89	0.000	-2.00	1.07	-4.11	0.11	0.064	-2.00	0.68	-3.34	-0.66	0.004
Obese Class I	0.00	0.53	-1.05	1.05	1.000	0.00	1.05	-2.06	2.06	1.000	0.00	0.62	-1.22	1.22	1.000
Obese Class II	-1.00	0.58	-2.15	0.15	0.087	0.00	1.09	-2.15	2.15	1.000	-2.00	0.71	-3.40	-0.60	0.005
Obese Class III	-2.00	0.77	-3.51	-0.49	0.010	-1.00	1.52	-3.99	1.99	0.510	-2.00	0.92	-3.82	-0.18	0.031

*The BMI estimate is the estimated difference between the BMI category and the normal weight category.