Glucose and Cognitive Performance: The Effects of Glucose on Memory and Sustained Attention

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KELLY RICHARDSON

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ABSTRACT

The effects of glucose on tasks of declarative memory, and sustained attention were examined. These effects were also investigated with regard to the age of the participant. Standard glucose and placebo conditions were run, and also a natural history condition to analyse the possibility of a placebo effect. Twelve young and twelve older adults participated in the study. Over three separate morning sessions, participants ingested either the glucose or the placebo drink, or nothing for the natural history condition, and completed the cognitive tasks. The between-group factor was age of the participant (young or older adult). The within-group factor was the type of drink ingested (glucose, placebo, or natural history). The effects of glucose on the sustained attention task were investigated over time, divided into 10 x 2 min periods. No effects of drink were found in regard to overall task performance for either age group. There was one main effect for period on one measure of the sustained attention task. There was also an associated interaction effect for this measure. Trends in the data pointed towards the possibility of the existence of a placebo effect. The placebo condition yielded consistently better performance than the other two conditions on most tasks. These results were discussed in light of the possible existence of a placebo effect, and the condition-specific effects of glucose.

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PROLOGUE

The present study is one component of a broader spectrum of research, facilitated by Dr John Podd in collaboration with Crop & Food Research Limited, on the influence of nutrients on human performance. In the work presented here, the effects of glucose on declarative memory and sustained attention are examined.

A considerable amount of research has investigated the effects of glucose on human performance. Most of this research has focused on the effects of glucose on cognition, particularly memory. There are many inconsistencies within the data on glucose and cognition, the primary one being conflicting results between original studies and replication attempts.

The present study follows on from research by Culligan (2002) that examined the effects of glucose, fat, and protein on recall and mental arithmetic tasks. Culligan found no effects of the nutrients on performance.

The present study aimed to repeat the memory study conducted by Culligan (2002) who was unable to find any effects of glucose on paragraph recall. In addition, the effects of glucose on sustained attention were investigated to find out if the typical drop-off in performance over time could be halted or minimised. There has been very little research on the effects of glucose on cognitive performance other than memory.

INTRODUCTION

In recent years, the idea that some foods are 'functional' has emerged. Functional foods are foods that grant additional health benefits, over and above the nutritional value derived from them (Bellisle et al., 1998). One such health benefit is improved cognitive performance. There has been a considerable amount of psychological research on the ability of certain foods to influence cognitive and physical performance, as well as psychological state (Dye, Lluch, & Blundell, 2000). For example, research by Smith, Kendrick, and Maben (1992) found that the ingestion of caffeine lead to improvements on most cognitive performance measures. Hindmarch, Kerr, and Sherwood (1991) found that alcohol impaired performance on most cognitive and psychomotor tasks. Kruesi and Rapoport (1986) write that simple sugars can cause disturbances in cognitive performance and mood. Lieberman, Corkin, Spring, Gowdon, and Wurtman (1983) report that carbohydrates can produce a temporary elevation in mood. Some studies have examined glucose as a functional food, showing that it can benefit cognitive performance. However, not all of these studies have been able to produce glucose effects. This may be because the effects of glucose are small, or that they only emerge under certain conditions.

This thesis begins by describing what glucose is, and how it works. Then, the importance of glucose to the brain is explained, and the effects of glucose on memory and possible mechanisms for this are examined. Following this, a discussion of the effects of glucose on sustained attention is presented. The effects of task difficulty are outlined and some of the inconsistencies in glucose research discussed. Next, the possibility that the glucose effect is a placebo effect is considered, and finally, a rationale for the present study is provided.

What is glucose and how does it work?

Glucose is a sugar. Sugars are included in the molecular class named carbohydrates, which also includes starches and fibre (Wildman & Medeiros, 2000). Chemically, sugars can be divided into either monosaccharides (6 carbon atoms) or disaccharides (12 carbon atoms). Glucose is a monosaccharide, or simple sugar. In humans, most glucose is obtained from the ingestion of polysaccharides (18 or more carbon atoms) and other sugars, rather than monosaccharides (Blakemore & Jennett, 2001).

After ingestion, glucose is absorbed by the intestines. The glucose is then transported by portal blood, firstly to the liver, and then to the rest of the body (Berdanier, 2000). Following digestion and absorption, blood glucose (glucose dissolved in the blood) increases. The pancreas controls blood glucose levels through the release of insulin. Insulin enables cells to absorb glucose from the blood (Blakemore & Jennett, 2001).

After the ingestion of glucose, blood glucose levels rise steadily and peak approximately 30 min after ingestion. The pancreas controls the height of this peak, via the release of insulin. Blood glucose slowly returns to its baseline level over 2 h (Benton, Parker, & Donohoe, 1996). All glucose in excess of immediate energy requirements is converted to glycogen, a product that is stored in the liver and muscles (Berdanier, 2000). The conversion of glycogen back to glucose is called 'glucogenesis.' This process occurs in the liver and kidneys. If an individual's blood glucose drops below 4 – 6 mmol/L, their sympathetic nervous system will initiate the adrenal gland to release adrenaline, which then stimulates the liver to release glucose. Feelings of hunger will also occur to encourage the individual to ingest more glucose. The body can also make glucose using amino acids from the body's protein stores. However, all of these homeostatic processes are under genetic, hormonal, and dietary control; thus, there are individual differences (Blakemore & Jennett, 2001; Berdanier, 2000).

The importance of glucose to the brain

Glucose is an essential source of energy for the human body, especially the central nervous system. Neurons rely on glucose as their primary source of energy. This is because most other nutrients cannot cross the blood-brain barrier (Zigmond, 1999). While the human brain accounts for only 2% of the body's weight, it consumes approximately 20% of the body's energy (Benton & Nabb, 2003). Therefore, the brain requires a constant supply of glucose for energy. For an adult, this is approximately 6 g each hour. If an insufficient amount of glucose is consumed to keep up this rate of supply, then glucose can be provided from within the body, as described earlier. Therefore, it is unlikely that the brain would not have sufficient glucose to carry out its operations.

Since glucose is the brain's primary energy source, anything that alters glucose levels may also alter brain functioning. There is a wealth of evidence supporting this proposition. For instance, hypoglycaemia (low blood sugar) is characterized by slowed reactions, difficulty concentrating, and other symptoms of cognitive disruption. Hyperglycaemia (high blood sugar) can also have an adverse effect on cognitive functioning (Berdanier, 2000).

Holmes (1986) looked at cognitive performance in males with insulin dependent diabetes mellitus (IDDM). Individuals with IDDM need exogenous insulin administration, along with good dietary management and regular exercise, to live. Holmes found that, in her sample, poor metabolic control was associated with mild cognitive deficits. In particular, memory and reaction time deficits were observed. Another form of diabetes is non-insulin dependent diabetes mellitus (NIDDM). Dye et al. (2000) write that cognitive impairment is present in individuals with both types of diabetes. They link this cognitive impairment to the lack of glucose availability. Cognitive deficits due to a lack of glucose availability can also occur in healthy individuals. In adults, missing breakfast has been associated with deterioration in

spatial memory, immediate word recall, and reaction time (Dye et al., 2000; Bellisle et al., 1998; Kanarek, 1997). Memory performance in adults 2 h after consuming breakfast correlates with their blood glucose levels (Benton & Nabb, 2003). Breakfast typically leads to improvements in cognitive performance, especially if the breakfast is high in carbohydrates (Bellisle et al., 1998; Kanarek, 1997). Carbohydrates are easily converted to glucose (Berdanier, 2000). Benton and Parker (1998) found that the adverse effects of missing breakfast could also be reversed with the ingestion of a glucose drink.

More evidence supporting a link between glucose and brain functioning involves dementia of the Alzheimer's type (DAT). DAT is a degenerative disorder which is characterized primarily by severe memory loss, but which also shows abnormalities of the glucose systems (Craft, Zallen, & Baker, 1992). Studies using positron emission tomography, a technique used to observe brain function, have shown that individuals with DAT revealed significantly more lateral asymmetry in their glucose metabolism than an age-matched 'normal' sample. The areas of the brain in which metabolic dysfunction occurred were areas associated with aspects of memory (Butters & Delis, 1995). Morley (2001) writes that, in individuals with DAT, memory is improved after an increase in plasma glucose concentration. Another dementia, known as Korsakoff's dementia, is also characterized by memory impairment (Butters & Delis, 1995). Korsakoff's dementia is due to prolonged thiamine deficiency, causing neurons to die. Thiamine is required to metabolize glucose; thus, the result is an inability to use glucose (Kaplan & Sadock, 1998).

In summary, there are several conditions linking memory performance and glucose availability. From an evolutionary perspective, this makes sense because if nutrient ingestion has memory-enhancing effects, then this allows the organism to recall the location of food (Kaplan, Greenwood, Winocur, & Wolever, 2000).

Glucose and memory

A review of the literature on glucose and its effects on memory revealed a considerable amount of research showing that memory can be enhanced by glucose. Research has shown that glucose can enhance several different types of memory, but recall memory in particular. The present study concentrates on recall memory (as opposed to recognition memory) and, therefore, will mostly review the recall memory literature. Memory is a broad term encompassing the encoding, storage, and retrieval of information in the brain. Theorists have divided memory into many subtypes. One subtype is declarative memory, which refers to the acquisition of information, facts, and experiences (Butters & Delis, 1995). Most research on glucose and recall memory has employed measures of declarative memory (for example, paragraph recall tasks); thus, most of the research discussed in this paper involves measures of declarative memory.

Typical research on glucose and memory employs a repeated measures, counterbalanced, crossover design. Generally, after an overnight fast, participants consume either glucose or a saccharin/artificially sweetened solution (sometimes called the 'placebo'), usually in the form of a drink. The participants are unaware as to whether they have consumed the glucose or the placebo. Participants perform cognitive tests at least 15 to 20 min after the administration of glucose. A week or more usually separates test sessions. A performance difference between the two groups is assumed to be due to the glucose ingested by the participants in the treatment group. Most of the research cited in this paper employed research designs similar to the aforementioned.

Benton and Owens (1993) found that ingestion of a glucose drink improved performance on a word recall task. Their participants were administered either a glucose or a saccharin drink, and then asked to recall a word list. There was a significant positive correlation between the

blood glucose level of participants and the number of words they recalled. However, Benton and Owens state that glucose improved word recall regardless of initial blood glucose levels. Foster, Lidder, and Suenram (1998) administered either glucose, saccharin, or water to a young female sample. The participants' performance on a free and a cued recall task was measured. Participants performed better on both tasks in the glucose condition than in the saccharin and water conditions. The participants still performed better in the glucose condition even if the participants' baseline blood glucose levels were controlled for. These studies (Foster et al., 1998; Benton & Owens, 1993) offer important results regarding the importance of baseline blood glucose levels.

Research by Kaplan et al. (2000) also employed recall measures. In their study, participants were administered carbohydrate as either glucose, potato, or barley; or they received a saccharin placebo. Their aim was to determine if glucose enhanced cognition in an elderly sample, and if dietary carbohydrates (potato and barley) had the same effect. They employed a word recall task and a paragraph recall task as measures of memory, as well as a visuomotor task, and an attention task. Their research found that performance after the consumption of carbohydrates (including glucose) did not significantly differ from performance after the consumption of the placebo on any of the cognitive tasks. However, the participants' baseline scores and β cell function did correlate with participants' improvements on the paragraph recall task; thus, the poorer the baseline score or β cell function, the more improvement was shown on this task. β (beta) cells are any secretory cells that are distinguishable by the characteristic of staining readily (Pease, 1986). Kaplan et al. do not define 'β cell function' in their report, but state that they obtained the measurement using 'Homeostasis Model Assessment'. Kaplan and colleagues concluded from this study that glucose only improves performance in an already impaired sample. Kaplan et al. can be criticised for their inability to define β cell function, which is an ambiguous term. Also, they

failed to employ a planned comparisons approach, in that, after obtaining non-significant results, they performed many post-hoc tests to find a significant result.

Suenram-Lea, Foster, and Durlach (2002) looked at the effect of glucose administration on memory performance in a sample of 60 young adults. Word list recall, working memory, and spatial memory were all measured. They found that glucose enhanced performance on all of these measures, regardless of whether the glucose was administered before or after learning the task. Suenram-Lea et al. write that this memory enhancement can be observed up to 24 h after glucose administration. This research highlights the possibility that glucose may influence all three (encoding, storage, and retrieval) aspects of memory. Sommerfield, Deary, and McAulay (2003) compared the performance of a group of healthy adults with induced hypoglycaemia to a group of adults with normal blood glucose levels on immediate and delayed declarative memory, immediate and delayed visual memory, and working memory. It was found that hypoglycaemia impaired performance on all of the measures of memory, but delayed memory in particular. This research suggests that glucose influences specifically the retrieval aspects of memory, as the delayed tasks showed more improvement. These studies (Sommerfield et al., 2003; Suenram-Lea et al., 2002) lead us to question when the administration of glucose would be most effective (i.e., prior to encoding, or prior to retrieval).

Recall memory tasks usually assess declarative memory. Craft, Murphy, and Wemstrom (1994) suggest that the memory-enhancing effects of glucose are limited to declarative memory. Their research showed that glucose had a memory-enhancing effect on a declarative memory task in males, but that other memory measures, including working memory and procedural learning measures, revealed no such effects. Manning, Parsons, Cotter, and Gold (1997) also found that glucose improved performance on measures of declarative memory, but not on non-declarative memory measures. Research from Manning, Hall, and Gold (1990) supports these results. They administered either glucose or saccharin

to an elderly sample, and then assessed memory, attention, and motor performance using neuropsychological tasks. Their results revealed that glucose enhanced performance on declarative memory tasks, but not on any of their other tasks. Previous research suggests that the effects of glucose on memory are limited to functions affected by the medial temporal lobe, and the hippocampus and surrounding areas. Declarative memory is a function facilitated by both the medial temporal lobe and the hippocampus (Benton & Nabb, 2003). So, some disagreement regarding the conditions under which glucose exerts an effect on memory is evident in the literature. There is also some question as to whether administered glucose actually influences memory at all.

In a review of functional foods, Bellisle et al. (1998) reported 6 studies in which the influence of glucose on memory in human subjects had been studied. All 6 of these studies found that glucose enhanced aspects of memory. Three of these studies employed young adults for their sample, and 3 employed an elderly sample. Bellisle et al. write that as glucose enhanced memory across an assortment of blood glucose levels, then the enhancement of memory could not be due to a prior state of hypoglycaemia. Bellisle et al. suggest that glucose can enhance other types of memory, despite findings to the contrary (e.g., Manning, Parsons, et al., 1997; Craft et al., 1994; Manning et al., 1990). Another type of memory that may be enhanced by glucose is short-term (or working) memory. Martin and Benton (1999) examined the effect of a glucose drink on a working memory task. Their participants were divided into a group who had consumed breakfast, and a group who had not consumed breakfast. Participants were given either a glucose or a saccharin drink. Their results revealed that glucose only enhanced performance on the working memory task in the group who had not consumed breakfast. This finding contradicts the assertion that baseline blood glucose levels are not associated with cognitive performance (Foster et al., 1998; Benton & Owens, 1993).

An important study by Fischer, Colombani, Langhans, and Wenk (2001) examined the effects of macronutrients on cognitive performance. This study is described in some detail because it is of relevance to the present study. They compared protein, fat, and carbohydrates (glucose) by measuring their influence on both simple and choice reaction time tasks, as well as a short-term memory task combined with a peripheral attention task. These tasks were simultaneously presented via a computer. A repeated measures, counterbalanced, crossover design was employed. Their sample consisted of 17 males, with a mean age of 26.5 years. After an overnight fast, participants ingested a protein, fat, or carbohydrate meal. They then completed the cognitive performance tasks. No macronutrient effects were found on the simple reaction time task. Fischer et al. reasoned that the simple reaction time task was not sensitive enough to identify differences between the macronutrient conditions, as the task only required a simple decision of either to react or not to react. On the choice reaction time task, glucose improved reaction time for the first hour of the task, but worsened reaction time for the second hour of the task compared to the protein and fat conditions. For the short-term memory task, the glucose condition was associated with higher accuracy, but for the peripheral attention task, glucose was associated with lower accuracy. From these results, Fischer et al. concluded that good cognitive performance is associated with a balanced glucose metabolism.

Research conducted by Messier, Desrochers, and Gagnon (1999) looked at the relationship between glucoregulation and memory. For their research, participants were divided into a poor glucoregulation group and a good glucoregulation group. Participants were administered glucose or saccharin. In the saccharin condition, the poor glucoregulation group performed significantly worse than the good glucoregulation group on a word-learning task. There was no difference between the poor glucoregulation group and the good glucoregulation group in the glucose condition. Fischer and colleagues' (2001) and Messier

and colleagues' findings emphasize an association between good cognitive performance and healthy glucose systems.

Learning new information relies on memory functions. Some research has shown that glucose can improve learning ability, perhaps through its influence on memory. Research on animals has shown that glucose can enhance learning. Stone, Rudd, and Gold (1990) found that glucose enhanced retention of information in a memory task using mice and rats. The rodents were administered either glucose or a saline solution shortly after training on an avoidance task (a learning task which involves memory functioning). Retention of this task was enhanced in the glucose group compared to the placebo group. Rodriguez, Van Ausdle, Dhanens, and Mondragon (1993) replicated Stone et al.'s research, and also found that glucose enhanced retention on an avoidance task. Flint and Riccio (1999) found that glucose lead to improved performance on an avoidance task with infant rats, while Winocur and Gagnon (1998) showed that the administration of glucose to rats improved performance on a radial-arm maze (but not on other spatial learning tasks that were administered). Research from Duncan and Gaffney (2002) revealed that hypoglycaemia significantly increased the amount of time that rats took to complete a radial-arm maze. This finding was corroborated by Sommerfield et al. (2003) who found that hypoglycaemia impaired memory.

A study by Messier, Pierre, Desrochers, and Gravel (1998) highlights the dose-dependant actions of glucose. This is important as it may help to explain some of the inconclusive results in glucose research. Female participants were administered either glucose, saccharin, or water, and were then asked to complete a word learning task to assess memory. The amount of glucose administered to each participant was determined by the participant's weight (300 mg of glucose to every 1 kg of bodyweight). Their results revealed that glucose did improve performance on the word-learning task. Also, the ingestion of glucose appeared to enhance the primacy effect, so participants were more likely to recall words from earlier in

the lists if they had ingested glucose. This study raises an interesting point regarding individual differences in glucose systems. Factors such as body weight and nutritional intake are extraneous variables that require consideration in glucose research.

Regardless of the support for the memory-enhancing effects of glucose, there are some studies that have produced null results. Azari (1991) examined the effect of glucose on memory in 18 young male adults. Participants ingested 0, 30, or 100 g of glucose in a double blind, triple crossover design. Participants then completed a word recall task, via a computer. Azari found that glucose was not associated with performance on the word recall task, and also that blood glucose levels did not correlate with the test scores. Azari states that this research had enough statistical power to conclude that glucose did not enhance memory. Another study that produced null findings was conducted by Culligan (2002). Culligan investigated the effect of carbohydrates, protein, and fat, versus a placebo on cognition and mood in males. She compared a younger and an older age group on their performance on word recall, paragraph recall, and mental arithmetic tasks. She found that nutrient ingestion had few, if any, effects on cognition or mood. Culligan suggests that more research in comparable settings is required in order to clarify the relationship between glucose and memory.

By way of summarising, it can be said that, in general, most studies have shown that glucose enhances certain aspects of memory. However, there are discrepancies among the research findings. More research on glucose and memory is necessary to understand these discrepancies. One particular factor that needs further investigation is participant age.

Glucose, memory, and aging

Glucose has been shown to have memory-enhancing effects on several different populations, including individuals with schizophrenia (Stone, Seidman, & Wojcik, 2003), brain-injured individuals (Petersen & Skelton, 2000), and individuals with Down syndrome (Korol & Gold, 1998), as well as healthy adults (Fischer et al., 2001). A considerable portion of the research on glucose and memory has utilized elderly samples, because older adults generally have poorer memories, and poorer glucose regulation, as compared to healthy younger samples (Greenwood, 2003).

The effects of glucose are more observable in vulnerable or undernourished populations (Bellisle et al., 1998). Kaplan et al. (2000) conclude that glucose only improved performance in impaired samples. Kaplan and colleagues' research demonstrated that glucose only enhanced memory if the participants' baseline scores on cognitive tasks were low to begin with, or if the participants had poor β cell function. Changes in well-nourished populations (for example, healthy young adults) could be due to disruption of regular consumption patterns (Dye et al., 2000; Bellisle et al., 1998). This is a possible explanation for why older adult samples produce more consistent results in research on glucose and memory.

With advancing age, the brain loses neurons. Before 60 years of age, cognitive functioning has already begun to decline. At 60 years, dendrites begin to shrink, and the brain becomes less plastic (Zigmond, 1999). Memory, in particular, is affected. Korol and Gold (1998) state that memory declines with age in both humans and animals. Specifically, the ability to remember new information is diminished (Korol & Gold, 1998). Craik (1991) writes that recall memory is more impaired than recognition memory in older adults. There are several proffered theories to explain memory decline with older age. Grady et al. (1995) propose that older adults are less inclined to employ strategies for remembering information. They believe

the relevant brain structures still function well, but are not utilized anymore. Korol and Gold (1998) offer the opposing theory, namely that either the brain structures are absent or their functions are diminished. Bellisle et al. (1998) relate age-related decline to individual glucose regulation. Craft et al. (1994) support Bellisle and colleagues' assertion by stating that age-related impairment in memory is worse in individuals with poor glucose regulation. Parsons and Gold (1992) also report that memory deficits in older adults are due to neuroendocrine dysfunction, which includes dysfunction in glucose systems.

Kaplan et al. (2000) concluded that glucose only improved cognitive performance in impaired samples. Older adults could be considered an accessible, and ethical, 'impaired' (in cognitive function) sample to employ for research on glucose and memory. Kaplan and colleagues' study did employ older adults for participants. They found that glucose enhanced declarative memory in older adults if baseline scores on cognitive tasks and β cell function were factored into the data. Research by Hall, Gonder-Frederick, Chewning, Silveria, and Gold (1989) compared younger (18 – 23 years) and older (58 – 77 years) age groups. They found that glucose was more successful in enhancing memory in older adults. Hall and colleagues administered a glucose or a saccharin drink to the participants. The participants then completed a memory task from the Wechsler Memory Scale. Their results revealed that glucose improved performance on the memory control task for both age groups, but the effect was stronger for the older age group. They also found that poor blood glucose control was associated with age-related memory impairments. Healthy glucose control is displayed if blood glucose falls rapidly following its initial rise after the consumption of glucose (Benton & Nabb, 2003). Manning, Stone, Korol, and Gold (1997) investigated the effect of glucose on delayed recall in an elderly sample. Their participants ingested glucose or saccharin, either before being read a paragraph or 24 h later when they were asked to recall the paragraph. Participants recalled more information from the paragraph if they had ingested glucose, regardless of the time they were given the glucose. This means that glucose could act on

encoding, storage, and retrieval of information. This research is supported by Suenram-Lea et al. (2002) who also found that the time of glucose ingestion had no impact on the memory-enhancing effects of glucose.

Parsons and Gold (1992) investigated the effects of glucose on memory in an elderly sample. The participants ingested drinks containing 0, 10, 25, or 50 g of glucose, or saccharin. The sample was then assessed using the Wechsler Logical Memory (WLM) test. It was found that glucose enhanced memory in an inverted-u dose-response curve. Twenty-five g of glucose was associated with the best scores on the WLM test. Less or more than 25 g was associated with lesser scores on the WLM test. Higher levels of blood glucose could lead to hyperglycaemia, which is associated with cognitive impairment, while lower levels may not have been high enough to increase blood glucose levels significantly (Blakemore & Jennett, 2001). Ragozzino, Unick, and Gold (1996) also found glucose to enhance memory in an inverted-u dose-response pattern, in their research on rats. It is suggested that the optimal blood glucose level for memory enhancement is 8 – 10 mmol/L (Greenwood, 2003).

A debate about whether glucose enhances only declarative memory or non-declarative memory as well is apparent from the opposing views reported in the literature. Manning et al. (1990) carried out a study employing an elderly sample. Their results revealed that glucose enhanced performance on measures of declarative memory, but not on non-declarative memory measures. Allen, Gross, and Aloia (1996) found that glucose enhanced performance on both memory and non-memory tasks in an elderly sample. Their participants were administered either glucose or saccharin, and then tested using the Rey/Taylor figure and a divided attention task. The glucose condition was associated with greater recall on the Rey/Taylor figure, and better performance on the divided attention task. Culligan's (2002) research compared younger and older age groups' performance on declarative memory. She found the expected differences between the age groups on performance of the paragraph

recall and word recall tasks, but no evidence that glucose enhanced memory at all. Despite negative findings such as these, glucose research generally shows that glucose can enhance memory in older adults (Korol & Gold, 1998). Understanding the mechanisms by which glucose affects memory could help us to understand some of the discrepancies in glucose research on memory.

In summary, a considerable portion of glucose research has employed older samples. Most glucose research using older samples has produced positive results, lending support to the theory that glucose has a stronger influence on impaired populations.

How does glucose influence memory?

There are several proposed theories as to how glucose exerts its influence on memory. The most popular of these theories involve the vagus nerve and the neurotransmitters, acetylcholine and epinephrine. Mental and physical arousal both cause an individual's heart rate to increase. For mental arousal, Turner and Carroll (1985) describe the increase as more than what is somatically required for the task. They suggested that the excess increase in heart rate is to help deliver more glucose to the brain. Kennedy and Scholey (2000) support this deduction with the observation that heart rate increases after the ingestion of glucose, but not after the ingestion of a placebo. Kennedy and Scholey note that, with increased heart rate, peripheral glucose levels decrease. They suggest that this decrease is due to more glucose being delivered to the brain. Also, heart rate increases more on harder tasks than on easier tasks, suggesting that harder tasks require more glucose. Blood glucose levels also decrease more rapidly with harder tasks (Backs & Seljos, 1994). Curiously, the memory-enhancing effects of glucose may be observed regardless of the amount of glucose in the brain (Kaplan et al., 2000).

The gut-brain axis, including the vagus nerve (cranial nerve X), has been implicated in several theories on how glucose enhances cognition (Kaplan et al., 2000). Gastrointestinal hormones are released after food ingestion. Some (for instance, cholecystokinin) are known to act as neurotransmitters, hormones, or neuropeptides in the brain (Flood & Morley, 1989; Flood, Smith, & Morley, 1987). These gastrointestinal hormones stimulate the vagus nerve. The gut is hypothesized to communicate with the brain via the vagus nerve. It is suggested that the vagus nerve communicates to the brain that glucose has been ingested and will soon be available for use. Flood et al. (1987) demonstrated this by cutting the vagus nerve in mice, which reduced the memory-enhancing effects of glucose. Flood et al. found that, in mice, cholecystokinin–octopeptide (a hormone released during feeding) increased memory retention. This effect is blocked if the vagus nerve is severed. The liver also delivers blood glucose information to the brain stem, using the vagus nerve. Similar information also passes through the celiac ganglion. Damage to the celiac ganglion has been linked to a decrease in the memory-enhancing effects of glucose (White, 1991).

Glucose is required to synthesize neurotransmitters, including acetylcholine and epinephrine. Acetylcholine has a role in the modulation of memory. Acetylcholine (cholinergic) antagonists have a negative effect on memory, whereas cholinergic agonists have a positive effect. Glucose acts as a cholinergic agonist; therefore, it has a positive effect on memory. If there is a decrease in glucose availability, acetylcholine availability also suffers, leading to dysfunction (Hall et al., 1989). Also, increased blood glucose has been demonstrated to augment cholinergic functions (Manning et al., 1990). DAT has consistently been demonstrated to be associated with depleted cholinergic neurons (Benton & Nabb, 2003). Epinephrine enhances memory in several ways, including by stimulating the vagus nerve, which communicates with the brain regarding glucose availability. Also, epinephrine promotes the transformation of glycogen into glucose to fuel the brain. Glucose can then stimulate the production and release of acetylcholine (Zigmond, 1999). Some research has

implicated insulin as the cause of memory enhancement, rather than glucose. Greenwood (2003) reports that insulin has been shown to improve memory in individuals with DAT. Interestingly, if the insulin response to glucose is suppressed, then there was no improvement in memory, presumably because without insulin the neurons cannot take up glucose. Therefore, although the mechanisms by which the brain utilizes glucose to enhance memory are unknown, the vagus nerve, acetylcholine, epinephrine, and insulin all appear to play roles. All of these systems are important for memory, and are also reliant on glucose to some extent (as most brain functions are), so dysfunction in any of them could lead to memory impairment.

To summarise, glucose appears to have some beneficial influence on memory, especially declarative memory. This influence seems to be stronger in older samples. Although researchers are not entirely sure as to how glucose acts on memory, some theories are emerging that promise to yield interesting research in the near future.

Glucose and attention

The majority of research on glucose and cognition has focused on memory. However, some research suggests that glucose can also influence other cognitive functions, including attention (Donohoe & Benton, 2000; Kaplan et al., 2000). One task that theoretically should benefit from glucose ingestion is a sustained attention (or vigilance) task. For present purposes, sustained attention is defined as concentrating on a clearly specified, continuous performance task for a lengthy period of time (e.g., 20 min or more). It is usually assessed by search tests, digit symbol substitution, or the Stroop test (Dye et al., 2000). On any task, performance drops off over time (after approximately 20 min) (Campbell & Bagshaw, 2001). Conversely, blood glucose levels peak 15 to 30 min after the ingestion of glucose, and then slowly return to baseline over a 2 hr period (Kaplan et al., 2000; Benton et al., 1996).

Suenram-Lea et al. (2002) note that the cognition-enhancing effects of glucose can still be observed 24 h after glucose administration. Thus, the question is: can ingesting glucose prior to engaging in a sustained attention task alter the degree to which performance deteriorates with time?

Research indicates that glucose is associated with enhanced general attention. Benton, Owens, and Parker (1994) state that there are repeated findings that drugs that work by cholinergic mechanisms exert an influence on attentional functions. Fucetola, Newcomer, Craft, and Melson (1999) found that the administration of glucose enhanced performance on a short attention task in a sample with schizophrenia. Fischer, Colombani, Langhans, and Wenk (2002) compared carbohydrate and protein breakfasts for their influence on cognitive functions. They found that a carbohydrate breakfast, that increased blood glucose levels, was associated with improvement on a short attention task. Harakas and Foulds (2002) discovered that the administration of glucose improved performance on the Rapid Visual Information Processing task (a sustained attention task) in newly abstinent tobacco smokers. Topitsch, Schober, Wurst, and Kryspin-Exner (1998) found that children with IDDM demonstrated attention deficits when experiencing hypoglycaemia.

Benton et al. (1994) investigated the effect of glucose on attention in two studies on young adults. Their first study employed 70 female participants, with a mean age of 21 years. The participants ingested either a glucose or a placebo drink, and then completed the Rapid Information Processing task (RIPT). It was found that the glucose condition was associated with significantly better performance than the placebo condition. Their second study employed 50 male participants, also with a mean age of 21 years. The participants received either a glucose or a placebo drink, and were then administered a computerized version of the Stroop test. All participants had normal colour vision. It was found that performance on

the most difficult subtest of the Stroop test was significantly improved in the glucose condition, but not the placebo condition.

Allen et al. (1996) found that glucose improved performance on a short divided attention task in an elderly sample. Also with an elderly sample, Kaplan et al. (2000) found no main effects of glucose on a 20 min attention task. However, if their participants' baseline scores were taken into account, glucose was found to have a minimal effect on attention. Kaplan, Greenwood, Winocur, and Wolever (2001) found that glucose significantly improved performance on Trails (a measure of attention and motor function), especially in older adults. Flint and Turek (2003) write that increases in blood glucose modulated attention to an extent. They found that a large dose of glucose did not influence attention, but that a moderate dose could improve attention, as measured by the Test of Variables of Attention, and a continuous performance task.

Several studies have shown that while performance is enhanced on a sustained attention task by glucose, these effects are often not apparent until the end of a test session. For example, Donohoe and Benton (2000) tested 46 females for glucose tolerance. After the participants consumed breakfast, they were administered a 5 min computerised vigilance task. It was found that higher blood glucose levels were associated with an improvement on the vigilance task, but only toward the end of the test session. Benton (1990) also reports that glucose only influences sustained attention toward the end of a test session. Benton and Nabb (2003) described research where glucose improved performance on a driving task, but only after the participants had driven 70 km (at least 40 min).

McAulay, Deary, Ferguson, and Frier (2001) induced hypoglycaemia in healthy adults. Their participants were administered the Test of Everyday Attention and Raven's Progressive Matrices. It was found that hypoglycaemia was associated with deficits in attentional flexibility

and speed of information processing, but that sustained attention was preserved. Fischer et al. (2001) found that glucose was associated with lower accuracy on their peripheral attention task. Manning et al. (1990) gave older adults either a glucose drink or a placebo drink, and then administered a series of neuropsychological tests, including a measure of attention. They found that glucose had no effect on their measure of attention. The findings from glucose research on attention appear less promising than the memory research. Nonetheless, there is evidence to suggest that glucose can influence some aspects of attention, under certain conditions. No research could be found on the influence of glucose on sustained attention. However, Donohoe and Benton's (2000) finding that glucose improved attention towards the end of a test session, is promising for future research in this area. Benton's (1990) research and a review from Benton and Nabb (2003) also support this as an area in need of future research.

Task difficulty

In many tasks used to assess cognitive functioning, performance tends to deteriorate as the tasks become more difficult. A number of researchers (Dye et al., 2000; Kaplan et al., 2000) have argued that a substance that might boost performance, such as glucose, could be expected to have its greatest effect when the cognitive load is greatest. Dye et al. revealed that glucose only improved cognitive performance if the performance tasks used to assess cognition were difficult enough. Bellisle and colleagues (1998) also label task difficulty as a modulating factor for research on glucose and cognition. Kennedy and Scholey (2000) suggest that "glucose preferentially targets tasks with a relatively high cognitive load" (p. 63).

Suenram-Lea et al. (2002) examined the influence of task difficulty on the cognition-enhancing effects of glucose. They tested healthy young adults on word recall performance. Participants were given either a primary memory task, or a primary memory task and a

concurrent secondary memory task. Their results revealed that glucose only improved performance on the primary memory task if participants were completing the secondary task as well. Donohoe and Benton (2000) found that a glucose drink improved performance on only the more difficult subtests of the Porteus Maze.

Task difficulty is a possible explanation for why Fischer et al. (2001) found that glucose enhanced performance on their choice reaction time task, but not on their simple reaction time task. Also, older adults need less difficult tasks than younger adults do to detect the cognition-enhancing effects of glucose. This is a possible explanation for why older adults improve more consistently on performance measures in glucose research (Kaplan et al., 2000). Culligan (2002) also looked at task difficulty, but did not find any significant effects of the glucose, regardless of the level of task difficulty. Craft et al. (1994) also found that task difficulty had no influence on the effects of glucose in their study. Despite Craft and colleagues', and Culligan's findings, task difficulty is generally accepted as an important factor to consider in glucose research. Possible reasons for inconsistent findings, such as these, are discussed next.

Inconsistencies

There are several inconsistencies within the literature on glucose and cognition. Firstly, there is disagreement as to whether glucose influences only declarative memory (Craft et al., 1994) or non-declarative aspects of memory as well (Fischer et al., 2001). Then, there are some negative results suggesting that glucose does not influence memory at all (Culligan, 2002). There is also opposing arguments for whether baseline blood glucose levels (e.g., Martin & Benton, 1999; Benton & Owens, 1993), task difficulty (e.g., Culligan, 2002; Donohoe & Benton, 2000), body weight (e.g., Messier et al., 1998), glucose dose (e.g., Azari, 1991), type of participant (e.g., Gonder-Frederick et al., 1987), and other factors moderate

the effects of glucose. There is also a mixture of results for whether glucose exerts any effects on non-memory functions, such as attention (e.g., Benton et al., 1994). Bellisle (2004) writes that performance on cognitive measures depends on many factors, such as individual ability, motivation, and previous learning. He also states that nutritional factors can play an important role in cognitive performance. His conclusion is that, given the large number of factors that can impact on cognitive performance, it is not surprising that glucose has not demonstrated consistent results. That is, the effects of a glucose supplement are not robust enough to show up under a range of different experimental conditions.

Researchers have proposed several reasons for these inconsistencies. Kaplan et al. (2000) suggest that they could be due to researchers' differing paradigms. This means that different researchers employ different methodologies based on their psychological beliefs. Kaplan et al. also state that different researchers begin testing at different times after the ingestion of glucose. Starting times have ranged from 15 min to 4 h after ingestion (Kaplan et al., 2000). Other methodological differences could also contribute to inconsistencies in results. For instance, differing research designs, operational definitions, tasks, difficulty levels, or populations could all influence outcomes. Kaplan and colleagues found that factoring in the baseline scores of cognitive tasks did alter the outcome of their study. If other research had factored in baseline scores, perhaps they would have achieved stronger results. Parsons and Gold (1992) discovered an inverted-u dose-response curve, suggesting that the glucose dose administered could influence outcome. They also suggest that response curves could be person-specific. Therefore, there are many factors that need to be systematically tested before the effects of glucose on cognition can be fully understood. One particular factor that has been almost completely overlooked is the extent to which a (presumed) glucose effect is a placebo effect.

The glucose effect as a placebo effect

In a typical glucose study, the control (or comparison) group receives a drink that has the same taste and degree of sweetness as the glucose drink, but contains no glucose. This control group is often called the placebo group. Research on glucose and cognition typically employs a placebo group. In glucose research, the placebo condition undergoes the same treatment as the glucose condition, except that the placebo condition does not receive any glucose. The placebo condition generally receives a saccharin or artificially sweetened solution with similar sensory properties to the glucose solution.

Stewart-Williams and Podd (2004) define a placebo as "a substance or procedure that has no inherent power to produce an effect that is sought or expected" (p. 326). They also state that a placebo effect is "a genuine psychological or physiological effect, in a human or another animal, which is attributable to receiving a substance or undergoing a procedure, but is not due to the inherent powers of that substance or procedure" (Stewart-Williams & Podd, 2004, p. 326). Thus, it is quite possible that participants in the placebo group develop the expectation that whatever it is that they are drinking will enhance their performance (just as placebo pills can produce strong anti-depressant effects) (Jospe, 1978). Therefore, if the placebo drink does improve task performance, then clearly, the difference between treatment and control group will be diminished. In other words, some of the effects of glucose may be masked by the placebo effect occurring in the control group.

Placebos have been demonstrated to exhibit strong effects. Kaplan and Sadock (1998) write that in up to 50% of placebo groups, a significant positive clinical effect is demonstrated. Moertel, Taylor, Roth, and Tyne (1976) reported that a sugar pill placebo was more effective than an oral analgesic in 112 cancer patients. Laska and Sunshine (1973) corroborated this finding. Robinson, Houtsmuller, Moolchan, and Pickworth (2000) reported that, in tobacco

smokers, the use of placebo cigarettes reduced tobacco craving and withdrawal. Eccles (2002) states that 85% of the effects of antitussive cough medicine are due to a placebo effect. It is possible that some (or all in some studies) of the effects of glucose are due to a placebo effect, but there is no research examining this possibility. As most studies compare glucose to an artificially sweetened placebo, Greenwood (2003) suggests that the provision of energy in any form could enhance cognitive performance.

Glucose does appear to exert some influence on some aspects of cognition. All the research cited thus far employed placebo conditions. Of the studies that produced positive results for a glucose effect, all were comparing a glucose condition to a placebo condition (e.g., Fischer et al., 2001; Kaplan et al., 2000; Martin & Benton, 1999). Therefore, glucose has been demonstrated to improve some aspects of cognition more than occurs in the placebo condition. Also, glucose is known to exert a physiological effect on the body. For instance, Kennedy and Scholey (2000) found that heart rate increased after the ingestion of glucose. Physiological effects such as this suggest that glucose does exert an influence on the body. However, the extent of the effects of glucose is difficult to determine because of the potentially confounding influence of the placebo effect.

To clarify the extent of a glucose effect, and the possibility of a placebo effect, research should include an experimental group that receives nothing – no glucose, no placebo, and no water. A group such as this is called a 'natural history' group. If a glucose condition and a placebo condition produce equal results, would this mean that the glucose had no effect? Or, that there was a placebo effect that partially masked the glucose effect? The inclusion of a natural history condition could help answer these questions. For the above example, if the natural history group also obtained equal results to the glucose and the placebo groups, then there is no evidence of a glucose effect or a placebo effect. But, if the results obtained by the natural history group were not as good as the results obtained by the other two groups, then

a placebo effect is suggested. If the natural history group obtained equal results to the placebo condition, but lesser results than the glucose condition, then a true glucose effect is indicated. Therefore, research employing a natural history group would be useful in helping to clarify the effects of glucose on cognition.

To this researcher's surprise, no glucose research involving a natural history condition could be found. Two studies employed a water-only condition, as well as glucose and placebo conditions (Foster et al., 1998; Messier et al., 1998). Both of these studies found that the glucose group performed significantly better than the placebo group and the water-only group. However, a water-only group is not a natural history group because the water itself may act as a placebo. Aside from these two studies, no further research involving more than a glucose group and a placebo group could be found. Therefore, the question of to what extent a (so-called) glucose effect is actually a placebo effect cannot, at present, be answered. The present study used a natural history group in an attempt to get a better understanding of these issues.

The present study

The present study was designed to extend and clarify previous research on glucose and cognition. In particular, the present study intended to investigate the effects of glucose on a declarative memory task, and a computerized sustained attention task, partially replicating the glucose component of the study by Fischer et al. (2001). To recapitulate, Fischer and colleagues examined the effects of a glucose meal (in the form of a spoonable cream) on a computerized simple and choice reaction time task, and a computerized short-term memory task combined with a simultaneous peripheral attention task. Seventeen young males were tested using a repeated measures, counterbalanced, crossover design. No glucose effects on the simple reaction time task were found, but glucose improved performance for the first

hour of the choice reaction time task. Glucose was associated with poorer performance on the second hour of the choice reaction time task. It was also found that glucose led to higher accuracy on the short-term memory task, but lower accuracy on the peripheral attention task.

The present study was also influenced by aspects of Kaplan et al.'s (2000) study. Kaplan and his colleagues tested the effects of a glucose drink on declarative memory, visuomotor, and attention tasks. They found that glucose did not improve performance on any of the tasks, unless baseline scores on cognitive tasks and β cell function were factored into the data. If baseline scores and β cell function were taken into account, then glucose did improve performance on all of their tasks, although only minimally on the attention task.

Research by Culligan (2002) (carried out in the Massey University laboratory) was based on these two earlier studies (Fischer et al., 2001; Kaplan et al., 2000). Culligan examined the effects of glucose on two declarative memory tasks and a mental arithmetic task in a younger and an older age group. She found that glucose had few, if any effects on any of her tasks; thus, she failed to replicate the earlier studies' findings, although she obtained the same results as Kaplan et al. when baseline scores and β cell function were not taken into account. Culligan's failure to replicate the positive effect of glucose on declarative memory was surprising. Following on from Culligan's research, the aim of the present study was to attempt again to replicate the effect of glucose on declarative memory. The present study utilized a similar paragraph recall task to assess declarative memory. It is not clear why Culligan was unable to replicate earlier findings. She used the same amount of glucose, and other design parameters were very similar to earlier studies.

Another aim of the present study was to look at the effects of glucose on a sustained attention task. Benton and colleagues (1994) examined the effects of a glucose drink on the RIPT and the Stroop test (both short attention tasks). They found that glucose significantly

improved performance on both tasks. Based on previous research that found glucose to have an association with improved performance on attention tasks (e.g., Allen et al., 1996; Benton et al., 1994), it was expected that glucose would enhance attention. As no research examining the effects of glucose on sustained attention could be found, the present study hoped to extend glucose research in this area by testing to see if glucose could minimize or prevent the drop-off in performance that typically occurs over time in sustained tasks.

No previous research has attempted to find out if the so-called glucose effect is partly due to a placebo effect. A third aim of the present study was to clarify the influence of the placebo effect in glucose research. This was achieved by the inclusion of a natural history group. Although there have been no previous investigations of the placebo effect in glucose studies, it was expected that the placebo group would perform better than the natural history group, thereby showing a placebo effect.

The present study employed participants from two different age groups. Previous research has shown that glucose supplements may have a greater effect on older participants (e.g., Kaplan et al., 2000). In the present study, it was expected that the older participants (50 – 65 years) would find the sustained attention computer task using a joystick considerably more difficult than the younger participants due to lack of experience with computer joysticks.

Method

Sample

The sample consisted of 24 healthy participants in two different age groups. Each age group was made up of an equal number of males and females. The mean age for the 12 participants in the younger age group was 20.8 years with a range of 18 – 28 years. The

mean age for the 12 participants in the older age group was 54.6 with a range of 50 – 65 years. Recruitment occurred via posters, and 'word of mouth' in Palmerston North city, New Zealand. All participants gave written informed consent (see Appendix B), after being fully informed about the study and all possible risks. Participants were informed via an information sheet (see Appendix A), and had the opportunity to ask questions. The study was reviewed and approved by the Massey University Human Ethics Committee, Palmerston North, New Zealand (PN Protocol – 03/66).

Inclusion criteria

Potential participants were included in the study if they met all of the following criteria, and none of the exclusion criteria. They were required to be in good health; to have English as their first language; and to be available for three consecutive morning sessions, each up to one hour, during the period of September to December 2003.

Exclusion criteria

Exclusion criteria were: diabetes, hearing or visual impairment, any neurological disorders, any psychiatric or psychological disorders, or any physical disorders that could impair cognitive, psychomotor or digestive functioning. Further, participants could not be taking any medications that could interfere with cognitive or psychomotor performance and/or digestion, or any anticoagulants. An objection to supplying blood samples was the final criterion. Information on inclusion and exclusion criteria was collected from each participant prior to the beginning of the study (see Appendix C).

Design

A single blind, counterbalanced, 3 x 2 mixed factorial design was employed for this study. The within-groups factor was the drink (either glucose, placebo, or natural history), and the between-groups factor was age (younger or older). This design was used to assess the effects of glucose on declarative memory and on a sustained attention task.

Participants experienced each of the conditions (glucose, placebo, and natural history) at one of 3 test sessions, and therefore acted as their own controls. The order the conditions were presented was balanced across participants and sessions to attempt to rule out order and practice effects. Table 1 summarises the design.

Table 1: Summary of design

		Between-group factor (Age)	
		Younger	Older
Within-group factor (Drink)	Glucose	N = 12	N = 12
	Placebo	N = 12	N = 12
	Natural History	N = 12	N = 12

Measures

Drinks

Participants received either a 300ml drink (glucose or placebo) or nothing at all (natural history). The glucose drink consisted of 260ml of water, 46.82g of glucose (BDH Anala R, BDH Laboratory Supplies, Poole, BH15 ITD, England) and 7.5ml of artificially sweetened

lime flavour cordial (Hansells New Zealand Ltd, Masterton, New Zealand). The glucose drink contained 774 kJ of energy. The placebo drink consisted of 292.5 ml of water and 7.5 ml lime cordial. Contents of all the drinks are summarised in Table 2.

Table 2: Drink contents

	Water (ml)	Lime juice (ml)	Glucose (g)	Total volume (ml)	Energy (kJ)
Glucose	260	7.5	46.82	300	774
Placebo	292.5	7.5	0	300	0

The present study used the same ingredients and quantities as Culligan's (2002) study. Culligan piloted these recipes to ensure both drinks were indistinguishable and of similar sweetness. The drinks were prepared the night before a test session and were presented in opaque cups with lids and straws. Participants had 5 minutes to consume the drinks.

Tasks

Memory

Declarative memory was measured using the memory test from the Wechsler Memory Scale (WMS) R and III (paragraph recall) (Wechsler, 1997). Two paragraphs from the WMS III, and one from the WMS R, were used. A fourth paragraph from the WMS I was used for training. The WMS is an individually administered instrument with a theoretical basis to evaluate memory (D'Amato, 2004). The reliability of the WMS III's 17 subtests ranges from .74 to .93 (D'Amato, 2004). The paragraph recall task employed in this study is from the Logical Memory subtest of the WMS; hence its reliability is acceptable. This task is unchanged from

the WMS R, except for the addition of a new paragraph (D'Amato, 2004). The WMS III utilized a standardization sample consisting of 1,250 individuals ranging from 16 to 89 years of age (Reynold, 2004). The inclusion of older age groups in the standardization sample means that the WMS is appropriate to use for the age groups employed in the current study.

Standardised instructions (see Appendix D) were read at the beginning of the task, and each participant had a practice trial on their training day. A different paragraph was used for each test session. The order in which they were used was randomised and balanced across participants and sessions. The task required participants to recall as precisely as possible a previously read paragraph. The paragraph was presented following the instructions detailed in the WMS III manual (Wechsler, 1997). Twenty minutes later, after the other tasks (see below) had been completed, the participants were asked to recall the paragraph, again using standardised instructions supplied in the WMS manual. Each participant's response was audiotaped for later analysis.

Sustained Attention

A computer programme, based on the computer task used by Fisher et al. (2001), was designed for the current study[1]. A white circle measuring 50 mm diameter was presented in the middle of a grey computer screen. This circle represented the home territory of a red spot (approximately 5mm in diameter) that was programmed to move in random directions and with random speeds out of the white circle. The participant's task was to counteract the movements of the red spot, trying to keep it in its home territory with the use of a standard computer joystick. The duration of the task was 20 min. The number of times that the red spot left its home territory (NTO), and the length of time that the red spot was out of this territory were measured to assess ongoing performance (LTO). A score was presented at the

[1] Thanks go to Mr. Malcolm Loudon, School of Psychology Workshop, Massey University for writing the computer programme.

bottom of the screen in an attempt to motivate the best possible performance from the participants. This score increased by 1 every second the red spot was in its home territory, and decreased by 10 every second the red spot was out of its territory. This score was not recorded.

To increase the information-processing load on the participants, 4 light-emitting diodes (LEDs) were mounted around the outside of the computer monitor, one at each corner of the monitor. The LEDs were programmed to switch on, one at a time, at random times and in a random order. The participants' task was to turn off the LED as quickly as possible using one of two push buttons on the joystick (RT). The upper button on the joystick extinguished either of the uppermost pair of LEDs; the lower button was used to extinguish either of the lower pair of LEDs. Performance was measured using the time taken (in ms) to switch off the LED. There was no maximum time.

This task occurred at the same time as the computerised task. So this task was also 20 min in duration. As an even number of each of the four lights had to be presented, and the interval between lights was a random time, the programme could not run for exactly 20 min. The programme would finish after the LEDs had been switched off 324 times, which was approximately 20 min. A participant's individual reaction time also caused some variation in the total time the dual task took to complete.

Standardised instructions were used to explain the dual task. Also, standardized dialogue was used to remind or encourage participants throughout the task. On their training day, participants were taught to use the programme, and were able to have a practice session. The computer programme was piloted to ensure that it was not too easy or too hard for both age groups.

Blood glucose

In order to be able to assess blood glucose levels across the duration of the task, blood glucose levels had to be taken at regular intervals during the task. The participants' blood glucose was measured 6 times (this includes a baseline) throughout each test session. Blood was gathered by finger prick using an Accu-check Softclix Lancet device. Blood glucose was determined using an Accu-check Advantage Systems meter and Accu-check Advantage test strips (Roche Diagnostics NZ Ltd., Mt. Wellington, Auckland, New Zealand).

Procedure

For the study, the participants were required to come to the laboratory on 4 consecutive days. Just one participant was tested at each session. The same laboratory was used for the entire study. Ambient lighting in the laboratory was adjusted to suit the individual preference of each participant.

The initial session was a screening and training session. This session took approximately 30 min. This session involved reading of the information sheet and answering any of the participant's questions. Participants were informed of all of their rights as a participant. The participant then read and signed the consent form and completed a biographical questionnaire (assessing inclusion and exclusion criteria). The participants were also administered a shortened training version of the computer task and a practice version of the paragraph recall task to be given during the experimental sessions, to familiarize participants with the tasks, and to attempt to minimize practise effects. Participants were offered the opportunity to have their blood glucose levels checked, to gain some familiarity with the procedure.

The experimental protocol took 45 min to 1 hr. Participants were required to come to the lab on 3 consecutive mornings at the same time. Participants were asked not to eat or drink anything (other than water) from 12 midnight the night before. Each session was completed following the same procedure.

Firstly, it was ensured that participants had not consumed anything since midnight the night before. Then, a blood glucose reading was taken at time 0 to establish a baseline measurement. Further blood glucose readings were taken at 10, 15, 20, 25, and 30 min after ingestion of the drink. These readings were still taken under the natural history condition. After the baseline blood glucose reading, participants were given either a 300mL drink (glucose or placebo) or nothing at all. Participants had 5 min to consume the drink. Participants were then asked to read (something from a selection of magazines) for 10 min. All the reading material provided was considered light reading. Ten min after ingestion of the drink, participants were read a paragraph for the paragraph recall task. They then completed the 20 min computer task. Blood glucose levels were measured at intervals throughout this task. At completion of the computer task, participants were asked to recall the previously read paragraph. After each morning's session, participants were provided with a light breakfast. After the fourth session, participants were debriefed regarding the order in which they had had the drinks. They were able to access a summary of the results from the study, as well as their individual results at completion of the study. Table 3 summarises the procedure.

Statistical Analysis

Descriptive statistics were gathered for all the blood glucose data, and line graphs were prepared to visually determine if the glucose drink did increase blood glucose levels.

Table 3: Summary of procedure

Time (minutes)	Screening/ training session	Session 2 - 4
0	Information sheet Questions	Baseline blood glucose measurement
5	Consent form Biographical questionnaire	Drink
10 15	Practice versions of cognitive tasks	2nd blood glucose measurement Paragraph read to participant
20		Start computer task 3rd blood glucose measurement
25		4th blood glucose measurement
30		5th blood glucose measurement
35		6th blood glucose measurement Finish computer task
40 45+		Recall paragraph Breakfast Debrief (4th session only)

All statistical analyses were performed using SPSS version 11.0.0; a statistics package for Microsoft Windows (SPSS, Inc., 2001). Descriptive statistics were gathered to examine scores on the declarative memory (paragraph recall) task, the number of times the red spot left its home territory (NTO), the time to return the red spot to its home territory (LTO), and the reaction time to extinguish the LEDs (RT) (computer task). Descriptive statistics were also used to examine the number of errors made in extinguishing the LEDs. Mixed design ANOVAs were used to determine if there were differences in performance across the different drinks (glucose, placebo, or no drink). In addition, the above data from the computer task were analysed for every 2 min (approximately) of the 20 min task to determine whether the glucose had any effect on maintaining sustained attention. Post – hoc tests (in the form

of Tukey tests or independent *t*- tests) were to be completed if any significant results were revealed. Statistical significance was set at $P = 0.05$.

Results

The present study investigated the effects of glucose on declarative memory and sustained attention. For declarative memory, participants' scores on the paragraph recall task from the glucose condition were compared to paragraph recall scores from the placebo and natural history conditions. For sustained attention, participants' performance on the computerized task was also compared across the glucose, placebo, and natural history conditions. This computerized task measured 3 variables which were: the number of times the red ball left its home territory (NTO), the mean length of time the red ball was out of its home territory (LTO), and the mean length of time participants took to extinguish the LEDs (RT). It was expected that the glucose condition would maintain better performance than the placebo or natural history conditions on these 3 measures throughout the sustained attention task.

Outliers

Data from the sustained attention task produced some very extreme scores that severely skewed the response distributions. For example, one participant took approximately 6 min (360,000 ms) to respond to the LEDs. These extreme scores tended to be from the same few participants. If any such extreme scores were present in a data set, then all of the offending participant's data were removed from that data set. The removal of 1, or in 2 cases, 2 participants' data removed most of the extreme outliers. No outliers were removed from the blood glucose or declarative memory data.

Blood Glucose

The mean blood glucose levels for each of the 6 times that blood glucose was measured, for both younger and older age groups, were calculated and can be seen in Figures 1 and 2. As these figures show, glucose administration did in fact raise blood glucose levels to the desired level. This level was sustained for the duration of the experiments. By comparison, the blood glucose levels in the placebo and natural history conditions were relatively low and unchanging.

Declarative memory

Two people scored the declarative memory task – the researcher and an assistant. For each test scored, the mean of the markers' 2 scores was recorded as the final score. The paragraphs were scored following the method described in the WMS III manual (Wechsler, 1997). Participants were given 1 mark for each piece of information they recalled, as determined by the manual. The paragraphs were scored out of different total amounts, so all scores were converted to percentages.

The inter-rater reliability of the markers was obtained using the intraclass correlation coefficient (SPSS Inc., 2001). The inter-rater reliability coefficient was .985, a very satisfactory level of agreement.

Table 4 summarizes the results from the declarative memory task. As expected, the younger age group obtained a considerably higher percentage of correct responses for the glucose, placebo, and natural history conditions, yielding a main effect for Age, $F(1,18) = 5.86$, $p = .03$. There appeared to be no effect of glucose on declarative memory performance.

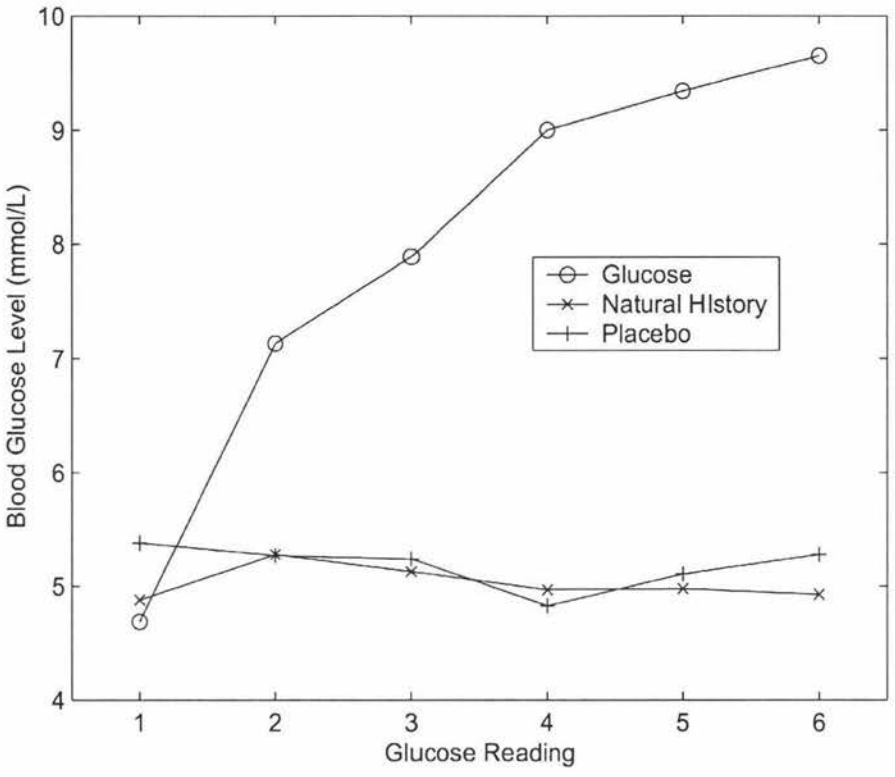

Figure 1: Mean blood glucose levels for the younger age group

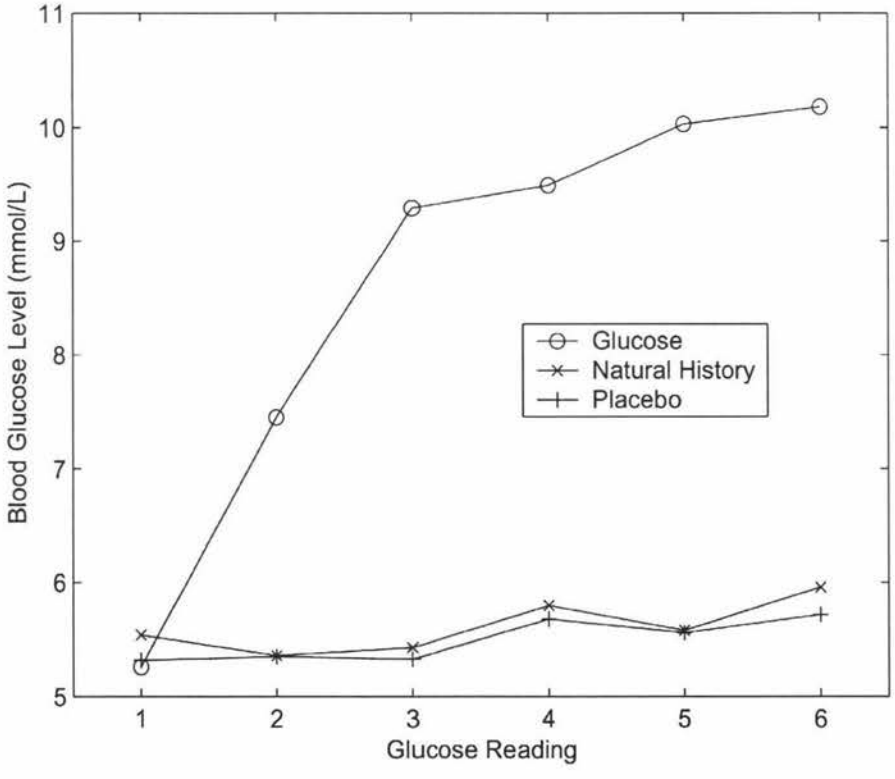

Figure 2: Mean blood glucose levels for the older age group

Table 4: Summary of results for the declarative memory task

	Younger age group		*Older age group*		*Overall*	
Condition	*Mean %*	*Standard Deviation*	*Mean %*	*Standard Deviation*	*Mean %*	*Standard Deviation*
Glucose	45.04	15.98	35.11	11.52	39.37	14.16
Placebo	47.29	19.40	33.84	12.77	39.89	17.07
Natural History	43.01	15.71	33.14	10.75	37.37	13.69

In fact, the younger age group scored slightly less (45.04%) in the glucose condition than they did in the placebo condition (47.29%). For the older age group, there was just over a 1% difference between the glucose and placebo conditions (35.11% and 33.84%, respectively). Thus, there was no main effect for Drink, $F < 1$; nor was there any interaction between Age and Drink, $F < 1$. Even though none of the mean differences were significant, it is worth noting that the placebo scores for both the younger and older age groups were slightly higher than those for the natural history condition; this was especially the case for the younger participants.

Sustained Attention

The data from the computerized sustained attention task were automatically collated by the computer. A specific computer programme was developed [2] to divide these data into 10 equal blocks of time (approximately 2 min each), so that the effects of glucose over time could be examined.

[2] This programme was written by Mr. Malcolm Loudon, Psychology Workshop, Massey University.

Number of Times Out of Home Territory (NTO)

Table 5 summarizes the results from the NTO measure of the sustained attention task. As expected, the younger age group, compared to the older age group, made considerably fewer excursions from the red ball's home territory for the glucose, placebo, and natural history conditions, giving a main effect for Age, $F(1,22) = 19.81$, $p < .001$.

Table 5: Summary of results for the mean Total NTO score in the Sustained Attention task

Condition	*Younger age group*		*Older age group*		*Overall*	
	Mean No. of excursions	**Standard Deviation**	**Mean** No. of excursions	**Standard Deviation**	**Mean** No. of excursions	**Standard Deviation**
Glucose	89.08	96.12	204.25	74.02	146.67	102.46
Placebo	74.83	92.55	209.58	78.13	142.21	108.41
Natural History	69.58	76.87	218.58	66.14	144.08	103.49

This result is at least partly due to the fact that the younger age group would be more familiar with computerized tasks, such as this. Mean scores for the younger age group are the reverse of those expected. That is, the glucose condition produced more excursions (89.08 excursions) than either the placebo (74.83 excursions) or the natural history (69.58 excursions) conditions. The older age group provided mean scores in line with expectations: the glucose condition produced fewer excursions (204.24 excursions) than the placebo (209.58 excursions) and the natural history (218.58 excursions) conditions. Unexpectedly, the variability in the data was very high, especially for the older age group. This variability was a general effect, and not due to 1 or 2 individuals. As a result, there was no main effect for Drink, $F < 1$, and no interaction between Age and Drink, $F < 1$.

Table 6 summarizes the results of the NTO measure from the sustained attention task over time. These results are divided into 10 x 2 min blocks, so period 1 is the first 2 min of the sustained attention task, period 2 is the second 2 min of the task, and so on. The main interest in splitting the data into blocks was to find out if the typical decline in performance across time in a sustained attention task could be modified with a glucose drink. The mean NTO values for each 2 min period do not appear to show a downward trend across periods. A 3-way ANOVA (Period x Age x Drink) confirmed this impression. As previously shown, there was a strong main effect for Age, $F(1,17) = 14.04$, $p = .001$, $\eta^2 = .44$. There was no main effect for Period, $F(9,153) = 1.16$, $p = .32$, $\eta^2 = .06$, or Drink, $F < 1$, and no interaction effects. Therefore, the main hypothesis for the present study, that glucose might aid performance in a sustained attention task, especially for older adults, was not born out.

Table 6: Summary of results for the mean NTO for each period in the Sustained Attention task

	Mean NTO											
	Glucose				**Placebo**				**Natural History**			
Period	Young		Old		Young		Old		Young		Old	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
1	11.27	10.82	23.75	6.36	8.00	11.33	19.13	9.54	8.45	8.08	21.00	8.00
2	8.91	11.62	21.63	7.96	9.64	10.02	17.88	8.98	7.00	8.82	19.13	10.02
3	8.82	9.68	16.50	6.70	8.18	9.57	19.38	9.52	7.91	9.06	21.88	11.95
4	10.00	10.62	20.63	6.05	8.82	10.90	18.00	8.04	8.45	10.25	22.13	8.74
5	8.00	8.40	21.13	7.95	7.18	9.53	20.13	8.91	7.55	9.11	21.38	10.60
6	9.09	8.98	22.00	5.78	7.64	9.30	19.50	8.77	6.36	7.99	18.00	11.08
7	9.82	11.40	19.75	9.85	7.73	10.70	19.75	6.90	6.18	7.39	21.75	10.15
8	8.73	10.82	17.38	9.38	7.09	11.24	22.00	9.35	7.91	8.30	21.63	7.05
9	9.00	9.12	18.00	6.41	7.27	7.93	18.63	8.75	6.09	8.40	20.88	7.62
10	11.00	11.87	20.13	8.10	7.27	9.44	18.38	8.48	9.09	10.80	22.00	11.54

The failure to find any statistically significant effects of glucose (or placebo) may have been due to the high degree of variability in the data, or because the effect sizes were too small to be detected at the levels of statistical power available. Another way of examining the sustained attention task data for trends is to fit regression lines to the data over the 2 min periods. For Figure 3 (and all following figures), 'G' stands for glucose condition, 'P' for placebo condition, and 'NH' for natural history condition. The amount of variance explained by the regression lines is expressed as *R*sq values in the appropriate figure. A preliminary investigation of the data showed that in all cases a quadratic (curvilinear) regression explained more of the variation than a simple linear regression. Thus, all fitted curves are curvilinear in nature.

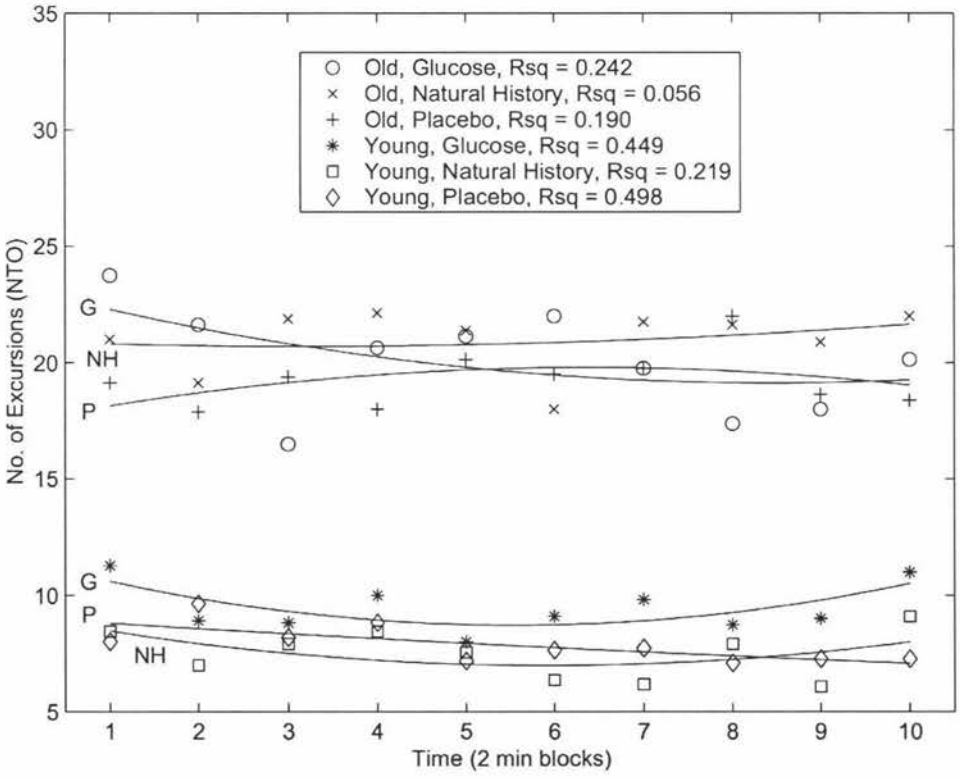

Figure 3: Mean NTO over time for younger and older age groups

Figure 3 plots the mean values shown in Table 6 as a function of the 2 min periods for both the older and younger age groups. Curvilinear regression lines have been fitted to the data points. One would expect that the natural history condition would produce the largest negative slope and the glucose condition the least, if glucose was improving sustained attention. As the results show, for the older age group, the glucose condition did result in better performance over time, whereas the placebo condition resulted in quite consistent performance throughout the task. The performance in the natural history condition declined over time. Regression lines accounted for 24% of the variance in the glucose condition, 19% in the placebo condition, and only 6% in the natural history condition. These results may indicate the existence of a small glucose effect and a small placebo effect, as the placebo condition resulted in better performance than the natural history condition. For the younger age group, the glucose condition revealed a slight u curve, which accounted for 45% of the variance. The placebo condition revealed a very similar u curve, which accounted for 50% of the variance. These patterns indicate that performance in the glucose and placebo conditions improved at first, but then began to decline towards the end of the task. This is the expected result for sustained tasks. Therefore, glucose did not appear to affect the performance of the younger participants. The variance explained by the regression is much higher for the younger participants compared to the older participants, reflecting the lower variability in their data.

Length of Time Out of Home Territory (LTO)

Table 7 summarizes the mean LTO from the sustained attention task across the whole 20 min task. As for the NTO measure, there was a clear effect of age for the LTO measure, $F(1,17) = 13.86$, $p = .002$, $\eta^2 = .45$. Older participants took between 3 and 6 times as long (on average) to return the red ball to its home territory compared to the younger participants. Once again, a main feature of LTO performance is the extreme variability in the data, especially for the older participants. Thus, even though some of the mean differences were

quite substantial (e.g., 1973 ms vs. 2888 ms for the placebo and natural history conditions, respectively, for the older age group) the amount of inter-participant variability meant that there was no main effect for Drink, $F < 1$, and no Drink x Age interaction, $F < 1$.

Table 7: Summary of results for the mean LTO score in the Sustained Attention task

Condition	*Younger age group*		*Older age group*		*Overall*	
	Mean ms	**Standard Deviation**	**Mean** ms	**Standard Deviation**	**Mean** ms	**Standard Deviation**
Glucose	499.29	62.49	1132.80	240.16	752.70	116.80
Placebo	493.00	69.16	1468.55	225.84	883.24	116.29
Natural History	455.91	54.67	2374.91	768.67	1223.51	311.12

Table 8 summarizes the results of the LTO measure from the sustained attention task across 2 min time periods. There was a significant main effect for Period, $F(9,162) = 5.68$, $p < .001$, $\eta^2 = .240$. However, this was qualified by a significant Period x Age interaction, $F(9,162) = 4.65$, $p < .001$, $\eta^2 = .21$. An examination of Figures 4 and 5 suggests this interaction arose because across the 10 time periods, performance was better (lower LTO scores) in the glucose condition compared to the placebo condition, but only for the older participants.

Figure 4 illustrates the performance of the younger age group over time on the LTO task. From this figure, it can be seen that the data are very variable and do not suggest any consistent effects of glucose or placebo. Figure 5 illustrates the performance of the older age group over time on the LTO task. From this figure, it can be seen that the glucose and placebo conditions both revealed slight u curves, indicating slow improvements at first, but with performance beginning to decline towards the end of the task. The natural history condition improved greatly at first, but then also began to decline towards the end of the task. These patterns demonstrate the expected performance on a sustained task. Therefore,

across time glucose appears not to sustain attention better than the placebo condition. However, the data are clear in showing the glucose condition consistently yielded better performance than the placebo and natural history conditions. Thus, the data for the older participants strongly suggest that glucose did aid performance. Further, the difference between the natural history and glucose conditions suggest a consistent placebo effect across the sustained attention task.

Table 8: Summary of results for the mean LTO for each period in the Sustained Attention task

	Mean LTO											
	Glucose				**Placebo**				**Natural History**			
Period	Young		Old		Young		Old		Young		Old	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
1	599.67	699.24	1730.00	195.52	590.17	567.26	1693.75	993.43	526.58	422.06	3801.50	4703.99
2	494.17	466.58	1188.38	487.04	525.42	483.50	1951.88	1298.33	398.42	365.51	3708.75	6380.08
3	436.33	359.50	1003.75	276.03	542.75	542.99	1538.75	871.80	467.08	392.20	2142.50	2818.57
4	394.08	367.02	1191.75	577.71	404.75	403.94	1293.50	810.02	440.92	394.02	2275.38	2707.55
5	488.83	305.91	927.25	376.72	487.50	465.10	1379.40	700.65	491.00	347.17	1826.37	1804.38
6	461.00	370.20	1000.38	404.66	590.08	697.69	1384.38	841.77	468.50	406.42	1867.25	1635.94
7	558.17	502.81	1129.38	535.95	505.08	390.74	1349.12	789.10	353.00	335.86	1914.62	2338.78
8	567.33	549.25	1012.75	419.15	423.42	453.94	1166.75	775.05	431.17	374.75	1753.75	1709.36
9	483.83	401.29	1242.00	726.57	427.17	309.13	1560.75	1371.71	531.00	372.56	1882.50	2079.79
10	509.50	308.74	902.38	419.18	433.67	352.68	1367.25	707.56	451.42	385.62	2576.50	4140.39

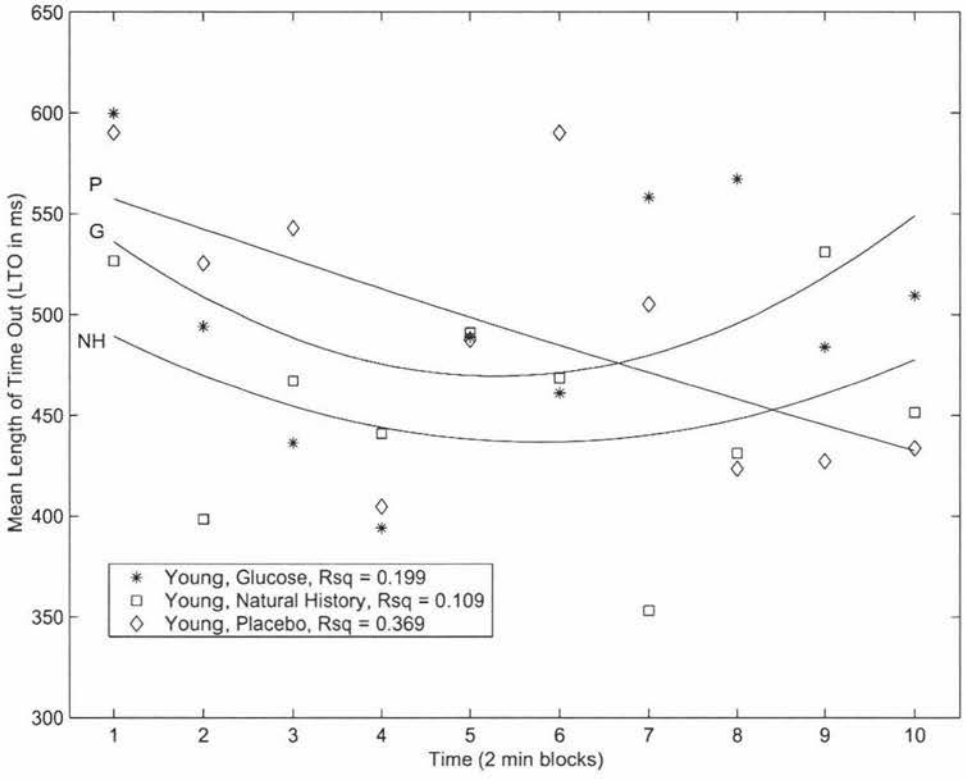

Figure 4: Mean LTO over time for the younger age group

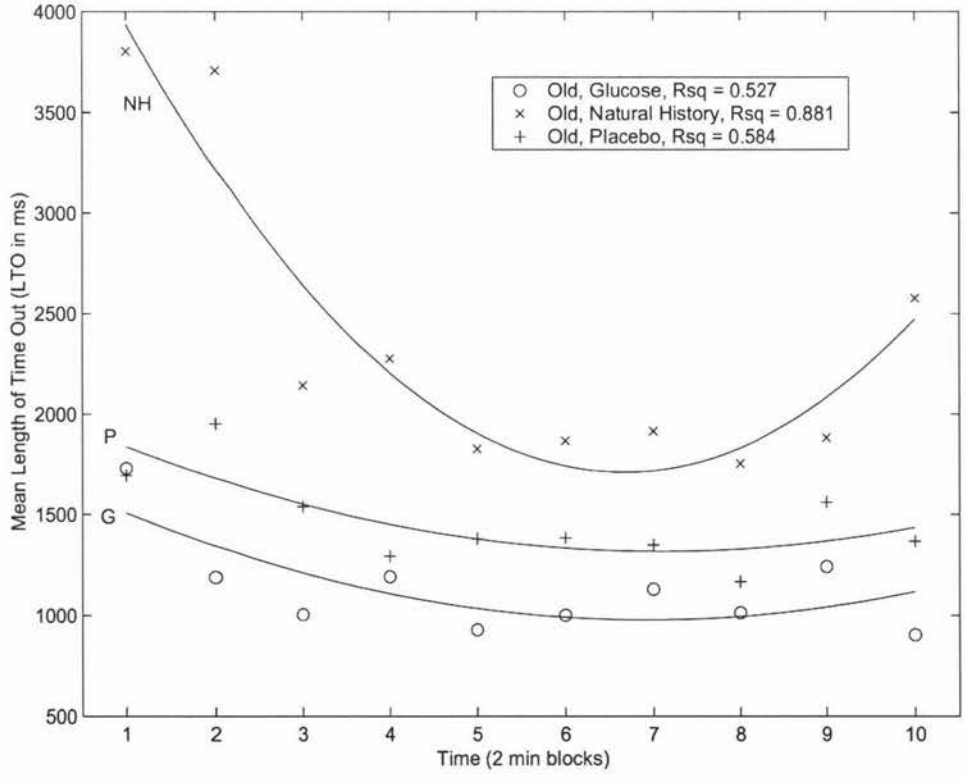

Figure 5: Mean LTO over time for the older age group

Table 9: Summary of results for the mean RT score (in ms) in the Sustained Attention task

Condition	*Younger age group*		*Older age group*		*Overall*	
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
Glucose	705.18	60.92	752.42	93.78	725.07	50.10
Placebo	667.02	21.66	659.05	21.69	663.67	14.46
Natural History	684.55	25.82	828.27	82.91	747.61	33.51

Table 9 summarizes the mean RT from the sustained attention task across the whole 20 min task[3]. The placebo condition yielded the fastest mean RTs for both the younger (667.02 ms) and older (659.05 ms) age groups. The glucose condition produced the slowest mean RT for the younger age group (705.18 ms), while the natural history condition produced the slowest mean RT for the older age group (828.27 ms). Despite the fact that there was at least a 30 ms difference between these conditions, there was no main effect for Drink because inter-participant variability was high (especially for the older group), $F < 1$. There was no Age X Drink interaction, $F < 1$. Surprisingly, there was no main effect for Age for RT, $F < 1$. However, the younger participants were slightly faster than the older participants in switching off the peripheral LEDs.

Table 10 summarizes the results of the RT measure from the sustained attention task across 2 min time periods. Figures 6 and 7 show the mean RT values from Table 10.

[3] A preliminary analysis of the error rates for the RT measure of the sustained attention task indicated that the number of errors over the entire 20 min task was too small to analyse.

Table 10: Summary of results for the mean RT for each period in the Sustained Attention task

	Mean RT											
	Glucose				**Placebo**				**Natural History**			
Period	Young		Old		Young		Old		Young		Old	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
1	692.27	195.96	669.13	126.42	647.45	145.43	694.38	283.54	657.73	136.59	768.50	322.12
2	645.09	108.65	805.00	277.84	723.09	291.50	666.00	84.31	658.64	178.19	945.62	503.46
3	637.64	145.03	704.13	75.38	657.55	173.11	686.63	204.23	673.55	173.29	803.13	395.63
4	846.00	603.56	765.63	185.58	667.45	162.52	676.13	155.88	700.45	224.88	790.75	207.61
5	671.91	120.09	986.88	865.05	650.55	136.04	653.63	69.50	703.18	173.24	740.50	220.35
6	735.55	190.68	768.50	160.71	675.27	197.26	629.63	94.75	679.64	147.78	946.88	520.46
7	721.09	189.88	707.63	170.46	662.45	167.94	640.00	91.80	653.00	138.12	673.00	146.55
8	712.00	213.31	660.00	101.81	655.18	130.72	644.63	137.85	650.74	130.05	695.36	146.61
9	731.91	201.67	725.00	159.35	672.82	158.81	638.63	62.67	658.42	125.86	740.00	234.56
10	658.36	130.09	732.25	182.44	658.42	138.02	660.88	90.83	663.18	186.70	707.26	333.85

Figure 6 shows the RT data across 2 min time periods for the younger participants. The data are very variable and do not suggest any consistent effects of glucose or placebo. Figure 7 provides the same data for the older participants. Here, the data suggest that RT in the placebo and glucose conditions is lower (better) than in the natural history condition.

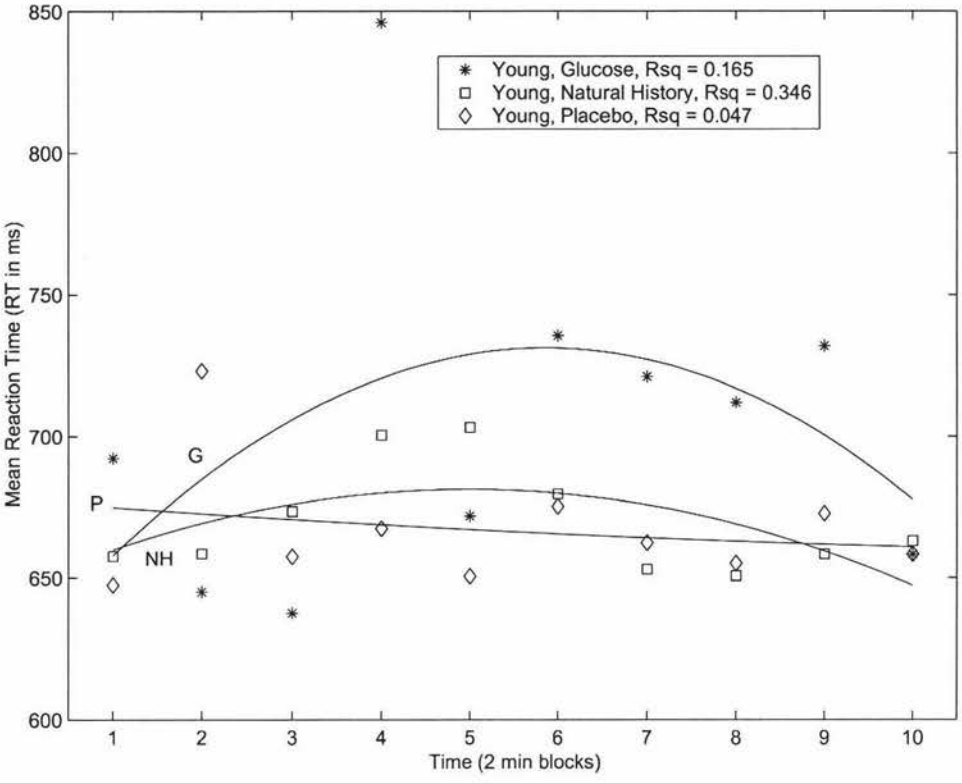

Figure 6: Mean RT over time for the younger age group

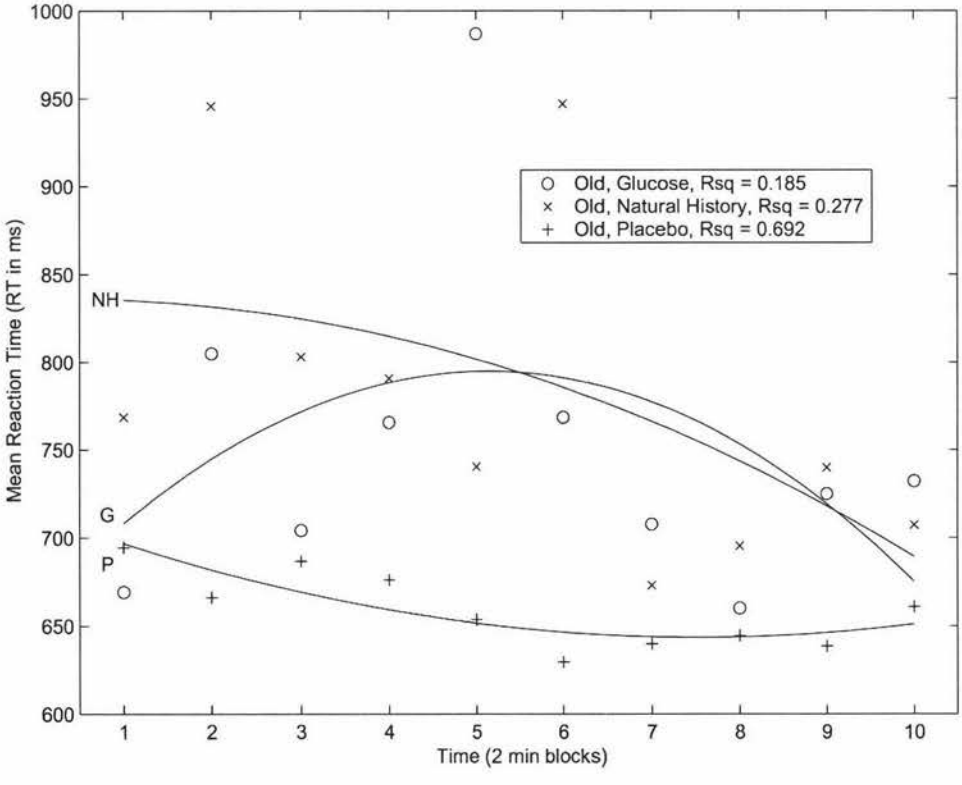

Figure 7: Mean RT over time for the older age group

However, the data are marred by some highly variable scores in some 2 min blocks, for instance, in period 5 for the glucose condition. In summary, performance on the RT task was more similar for the old and young participants than was performance on the joystick task (NTO and LTO).

Discussion

The primary objective of the present study was to determine if a small dose of glucose affected two aspects of cognitive performance: declarative memory, assessed by a paragraph recall task, and sustained attention, assessed by dual task performance over a 20 min period. Paragraph recall was unaffected by glucose, replicating the findings of an earlier study conducted at Massey University (Culligan, 2002). Furthermore, the glucose drink had a limited, but interesting, effect on sustained attention in the dual task, thus failing to replicate the findings of Fischer et al. (2001). These results held for both young and older participants.

The study also examined the possibility that the glucose effect could be attributed, at least partially, to a placebo effect, by comparing the effects of the administration of glucose, a placebo, and nothing (natural history) on the performance of the cognitive tasks. It was expected that the placebo condition would yield better performance than the natural history condition, thereby revealing a placebo effect. While there were no significant differences between the glucose, placebo, and natural history conditions, trends in the data appeared to indicate the possibility of a placebo effect.

In the following discussion the relationship between the results obtained by the present study and those obtained by previous research are discussed. Then, possible interpretations of these discrepancies are presented. Implications of the research findings are considered,

followed by a brief discussion on the strengths and limitations of the present study. Finally, some recommendations and suggestions for future research are proposed.

Blood Glucose

Blood glucose levels were analysed to determine if the glucose drink was raising blood glucose levels sufficiently, and to check that the placebo drink was not raising blood glucose levels at all. The glucose drink did raise blood glucose levels considerably, whereas the placebo drink had no effect on blood glucose levels. So, blood glucose levels were equivalent in the placebo and natural history conditions, but markedly elevated by the glucose drink, indicating the validity of the independent variable. As the administration of glucose lead to considerably higher blood glucose levels than the administration of the placebo, then it can be concluded that any effects of the placebo on cognitive performance could not be due to elevated blood glucose levels.

It can be noted that, after the administration of the glucose drink, blood glucose levels peaked after 25 or 30 min, which was towards the end of the test session. This was approximately when the participants were finishing the computerised sustained attention task, and recalling the paragraph for the declarative memory task. This was ideal because, at this stage, participants had been attempting to concentrate for nearly 20 min. As glucose is thought to have more of an effect towards the end of a test session, and on impaired or vulnerable samples, then these conditions should have been optimal to observe the effects of glucose on cognitive performance (Donohoe & Benton, 2000; Bellisle et al., 1998).

The large difference between the two age groups on declarative memory, NTO, and LTO was to be expected as cognitive functioning has been consistently shown to decline with age

(Zigmond, 1999; Korol & Gold, 1998). Therefore, the tasks were very successful in distinguishing between the performance of older and younger participants.

Declarative Memory

There was no significant main effect for the drink (glucose, placebo, or natural history) on the participants' scores for the declarative memory task; the glucose group and the placebo group obtained almost equal mean scores. The natural history group obtained a lower mean score, suggesting that they performed more poorly, but the difference did not reach statistical significance.

This finding parallels Culligan's (2002) finding that glucose had no effect on declarative memory. A considerable amount of research has demonstrated that glucose can enhance declarative memory (e.g., Manning et al., 1990; 1997a; Craft et al., 1994). However, Azari (1991) also obtained null results in research on the effects of glucose on declarative memory. Thus, previous findings have been somewhat mixed, suggesting that glucose has, at best, only a small effect on paragraph recall.

Craft et al. (1994) found that the administration of glucose improved performance on a paragraph recall task (similar to the one used in the present study), but only in their male participants, suggesting that glucose exerts more of an effect (or only an effect) on declarative memory in males. Manning, Parsons, et al. (1997) and Manning et al. (1990) both found glucose to have a beneficial effect on declarative memory. As neither of these studies examined sex as a variable, they are unable to refute this suggestion. Culligan (2002), however, employed only male participants, and yet found no effect of glucose administration on declarative memory. Martin and Benton (1999) also examined the effects of glucose on memory. They found that the benefits of glucose were apparent only if participants had not

consumed breakfast. In the current study, participants did not consume breakfast, but no beneficial effects of glucose were demonstrated. Potential reasons for the inconsistencies within glucose research are proposed later in the Discussion.

There was also no significant interaction between the drink and age in the present research, indicating that glucose had no effect on recall for both age groups. Glucose has been shown previously to enhance memory in older adults (e.g., Kaplan et al., 2000, Manning, Stone, et al., 1997, Parsons & Gold, 1992). Hall et al. (1989) found that glucose was more successful in enhancing memory in older adults than in younger adults. Hence, the present study's findings do not support those of the majority of previous research using older adults. However, Culligan (2002) also found that glucose had no effect on declarative memory, regardless of age.

Sustained Attention

The expectation that glucose would have a statistically significant effect on sustained attention was not supported by the present research. Sustained attention was assessed using a 20 min computerised dual task that required participants to keep a red ball inside its home territory using a joystick, as well as extinguish any LEDs that lit up around the perimeter of the monitor as quickly as possible, also using the joystick. The number of times the red ball left its home territory (NTO), the mean length of time the red ball was out of its home territory (LTO), and the mean length of time taken to extinguish the LEDs (RT) were all measured.

NTO

Glucose appeared to have no effect on the NTO measure. In fact, the glucose condition resulted in the worst performance on this measure. It was expected that glucose would

reduce or eliminate the drop-off in performance that typically occurs in sustained tasks (Benton & Nabb, 2003; Donohoe & Benton, 2000; Benton, 1990). When the sustained attention task was divided into 10 x 2 min periods, and analysed across the course of the task, it was found that there was no statistically significant change in performance across time. However, the effect size (η^2) was reasonably large (.599), suggesting a significant main effect may have been obtained with increased statistical power. Observation of NTO plotted over time (see Figure 3 in the Results section) is suggestive of a small glucose effect, as well as a small placebo effect, for the older age group. One unfortunate, and unexpected, aspect of the data was a very marked degree of variability both within and across participants. Future studies should attempt to reduce this variability, which may have masked any real differences across conditions.

LTO

As for the NTO measure, the overall LTO measure yielded no main effect for glucose. The standard deviations for these means were higher than the actual means, once again indicating an enormous amount of variation in the data. However, there was a main effect of period on LTO, but this has to be interpreted in light of a significant interaction between period and age, due to performance in the glucose condition being consistently better across time than performance in the placebo condition, but only in the older age group. This interaction supports previous research that has shown glucose to have more of an influence on older adults than younger adults (e.g., Kaplan et al., 2000, Hall et al., 1989). These results indicate that glucose may have an effect on some aspects of a sustained attention task, but only for older adults. Observation of LTO plotted over time (see Figure 5 in the Results section) supports this conclusion. Although the performance of all 3 conditions declined towards the end of the task, it can be seen that the glucose condition yielded consistently better performance than the placebo and natural history conditions.

Thus, performance on the LTO measure was significantly improved by glucose for the older participants, but performance on the NTO measure was not. Why was LTO affected by glucose administration but not NTO? The NTO measure involved just hand-eye co-ordination, whereas the LTO measure involved hand-eye co-ordination and processing information. Glucose administration did not influence hand-eye co-ordination, as, if it had, both measures (LTO and NTO) would have been affected. Perhaps decision making or processing speed was affected by glucose administration. If glucose were to improve decision making or processing speed, but not hand-eye co-ordination, the amount of times the red ball exited its home territory would remain unchanged, but the participant's realisation of the error, and the decision to correct it, would be faster. There seems to be little or no research on glucose effects that has analysed performance across time. Thus, before any firm conclusions are drawn, more research is required.

RT

The speed-accuracy trade-off, indicated by a positive relationship ($r = 0.14$) between RT (speed) and accuracy (the number of errors made), suggests that as RT increases, so does the number of errors made. The following results should be interpreted with caution because of this relationship.

The glucose drink had no effect on RT, either when the task was analysed as a whole, or when it was broken down into 2 min periods. Nor were there any significant interaction effects on RT. Once again, the data were highly variable and, as Figures 6 and 7 in the Results section show, no consistent trends across the sustained attention task emerged. There was also no significant difference between the performance of the younger and older participants.

Previous research on glucose and RT is limited but has, thus far, produced promising results. For example, Bellisle et al. (1998) reported 5 studies that had found low blood glucose to be associated with slowed RT (but not raised blood glucose with faster RTs). However, Owens and Benton (1994) found that high blood glucose was associated with faster RT. The present study found no evidence to support these previous findings.

To summarise, aside from the significant main effect of period on LTO, qualified by a significant interaction effect between period and age, there were no other effects of glucose arising from the sustained attention task. Overall, these results indicate that glucose may only enhance limited aspects of sustained attention. However, such a conclusion might be premature, as the following discussion will show.

Although no previous research has examined the effects of glucose on attention over time, the results from the present study conflict with assertions from previous research that glucose does improve general attention (e.g., Fischer et al., 2002, McAulay et al., 2001, Benton et al., 1994). McAulay et al. (2001) induced hypoglycaemia in healthy adults. Their participants were administered the Test of Everyday Attention and Raven's Progressive Matrices. It was found that hypoglycaemia was associated with deficits in attentional flexibility and speed of information processing, but that sustained attention was preserved. Conversely, Donohoe and Benton (2000) ascertained that glucose influenced performance on a sustained attention task, but only towards the end of the task. Other research has also emphasized that glucose only influences sustained attention after a certain amount of time (e.g., Benton & Nabb, 2003, Benton, 1990). The results from the present study do not support this claim, although the sustained attention task may not have been long enough to detect this effect. Nonetheless, the results from the present study support McAulay et al.'s (2001) finding that glucose has little effect on sustained attention, as compared to general attention.

The distinction between general attention and sustained attention is one of time. Sustained attention is defined as concentration on a clearly specified, continuous performance task for a lengthy period of time (e.g., 20 min or more). General attention is, therefore, concentration on a task, or tasks (not necessarily continuous), for a lesser period of time. As the amount of research on glucose and attention is limited, and findings are inconsistent, it is difficult to explain why the present study obtained the results that it did. Glucose may influence general attention, but not (or only some aspects of) sustained attention. If this is the case, attention may act similarly to memory, in that short-term and long-term functions are quite distinct. Or, the glucose effect on sustained attention may not occur until after 20 min.

There are several factors that may have influenced the data from the declarative memory task and the sustained attention task. Firstly, it is common practice to remove any data more than 2 or 3 standard deviations from the mean. Despite huge variance in the data, particularly in the RT aspect of the sustained attention task, it was decided not to truncate the data. The reason for this was that variance is 'part and parcel' of measuring RT, especially in the kind of task employed by the present study. A couple of participants performed particularly poorly on 1 or 2 aspects of the sustained attention task, so their individual data were removed. Aside from these individuals' data, no other outliers were removed. As a result of this, some of the standard deviations obtained in the present results are very large (for example, see the LTO component of the sustained attention task). The noisy data from the sustained attention task could be due to inadequate training prior to the experiment. These noisy data would have reduced the power of the present study, thus making it harder to obtain statistically significant results.

Statistical power is an important factor to consider in a more general sense. The present study employed sufficient participants to assess the effects of glucose on cognition, as the

same sample size as previous research employed was used (e.g., Culligan, 2002, Fischer et al., 2001). However, some of the results suggest that significant results would have been obtained with more statistical power. Statistical power can be increased by using more participants. An alternative to increasing sample sizes is to conduct meta-analyses. Meta-analyses combine all of the effect sizes from smaller scale research to see if they are significant overall. A meta-analysis of all of the glucose research that has obtained non-significant or weak results, such as the present study or Culligan's study, would help to determine if there were any 'hidden' significant results.

Thus, the present study may have obtained stronger results if the data had been less noisy. This variability could have been reduced with increased training on the sustained attention task. Another possible reason for the lack of significant results could be that the sustained attention task was too short. Longer sessions of the sustained attention task would test this hypothesis, and may also help reduce variability. The present study employed a small number of participants, and therefore had low statistical power, which also may have contributed to the failure of the present study to obtain strong results. As the glucose effect is probably not a robust effect, it would be prudent in future research to employ a large number of participants.

Possible Interpretations of Results

First, it may be that a glucose drink does not affect cognitive performance. However, while several previous studies have also obtained null effects, others appear to show that glucose can affect cognitive performance, especially when older participants are involved, or if task difficulty is increased (Kaplan et al., 2000; Bellisle et al., 1998). These mixed results suggest that if there is a glucose effect, it certainly is not a robust one.

No previous studies have included a natural history condition; the standard design is a glucose condition and a placebo condition (sweetened drink, but without the glucose). It is therefore impossible to say how much of any glucose effect is a placebo effect. Thus, a second possible interpretation of the results in this area is that some, possibly all, of the so-called glucose effect is in fact a placebo effect. However, the results of the present study do not support such an interpretation. There was no evidence for a consistent placebo effect when comparing the natural history and placebo conditions. But the current results are based on very noisy data and may not be a fair test of the placebo hypothesis. Better design sensitivity is required, along with greater statistical power. Trends in the present data suggest that a placebo effect may be involved. The placebo condition yielded the best performance on most measures. On the majority of the measures, the natural history condition yielded the worst performance. On most of the measures, the glucose condition and the placebo condition produced very similar results, while the natural history condition yielded slightly worse results. Perhaps with increased statistical power these trends would have been statistically significant, demonstrating a placebo effect.

The problem with the interpretation that the glucose effect is all due to a placebo effect is that it discredits a considerable amount of research that has consistently shown a glucose effect. That is, differences have been found between glucose and placebo conditions. This emphasizes the fundamental question in glucose research: why are results so inconsistent? Some research has obtained results that indicate that glucose does enhance cognition, and some research has not. One possibility is that glucose only has an effect on cognition under certain conditions. Bellisle's (2004) assertion, that cognitive performance is dependent on many factors, lends credibility to this explanation. Glucose may only benefit cognitive performance if particular factors are in play. If glucose is selective of the conditions under which it is effective, then this could explain the inconsistencies within the literature in this area.

Task difficulty is one condition that is associated with a glucose effect. Research on glucose and task difficulty suggests that glucose has more of an effect on difficult tasks (Dye at al., 2000). The present study attempted to maximize task difficulty with the inclusion of a sustained dual task. Another possible condition could be the characteristics of the sample employed. Research has demonstrated that glucose has more of an effect on impaired or vulnerable samples (Bellisle et al., 1998). It is possible that a glucose effect will only be achieved using some samples (e.g., older adults, individuals with schizophrenia). The present study employed an older age group, and showed that only this group appeared to benefit from the glucose, and then only on one sustained attention measure. One major weakness of the present research, and most of the previous research, is a lack of statistical power. Typically, studies run with only 10 – 20 participants in each condition. If, as almost all glucose research shows, the effects are small, then such a small sample will not consistently produce statistically significant effects.

Another factor that may have a major impact on the results obtained is the length of time between glucose ingestion and cognitive testing. Kaplan et al. (2000) report that different researchers began cognitive testing at different times after the ingestion of glucose (starting times ranged from 15 min to 4 h after ingestion). This may be another condition that influences the effectiveness of glucose. The present study began testing 15 min after the participants had ingested the glucose. This was the starting time that Kaplan et al. (2000), and Culligan (2002) had used in their research. Culligan asserted that more research in comparable settings is required before the glucose effect can be fully understood.

Implications

The most important implication from the results of the present study is that more research on glucose and cognition is required. More research employing a natural history condition will

help to clarify the probable existence of a placebo effect. Further, research could enable the exact conditions under which glucose is effective to be established. If the existence of a glucose effect, and the conditions that it is effective in, can be recognized, then there could be positive implications for research on dementia of the Alzheimer's type and other dementias. The mixed findings in this area suggest that the glucose effect is small. Therefore, future studies must pay particular attention to design sensitivity and statistical power if a glucose effect is to be consistently shown.

The results from the present research also lead us to question if all the glucose energy drinks on the market actually do as they advertise. The inconsistent results of research on glucose and cognition appear to show that glucose only influences 'mental ability' under certain conditions. Advertising such drinks may also contribute to the development of a placebo effect.

Strengths, Limitations, and Suggested Further Research

The present study design had several strengths. Firstly, the inclusion of a natural history condition was a novel design feature in glucose research. Research involving natural history conditions allows the possibility of a placebo effect to be examined. It is somewhat surprising that no previous glucose research had investigated a possible placebo effect. Another unique feature of the present study was the analysis of the effects of glucose over time. This is another area in glucose research that has, until now, been overlooked. This study utilised an independent variable check of blood glucose levels, which supports the validity of the findings. Also, methodological features, such as counterbalancing and the use of a single blind procedure, were employed to rule out the effects of extraneous variables.

Despite these strengths, there are some improvements that could be made if this research was to be replicated in the future. One fundamental limitation of the present study was the amount of training that the participants were given on the computerized task. There was some indication of practice effects in the results from the present study, as evidenced by improved performance over time, rather than the expected decline, in the sustained attention task. A serious problem was the possible confounding of practice effects with glucose effects. Any practice effects would have tended to improve performance across time in the sustained attention task, while the glucose effect may have caused the very same effect. Thus, it is unclear how much of the change in performance across time is due to a practice effect and how much is due to a glucose effect.

Also, some participants performed very poorly on this task, resulting in data having to be removed. Increased training on the computerised task would have eliminated practice effects before the actual experiment started. Increased training may have also helped to equalise the abilities of the participants, thereby reducing the potential for outliers in the data. Reduced variability (noise) in the data may have yielded significant results. Future research employing similar computerised tasks should maximise the amount of training participants are given.

The use of a dual task was another major limitation of the present study. It is suspected that participants did not divide their attention equally between the two tasks (e.g., the very slow RTs in responding to the LEDs in some of the older participants suggests that they were concentrating mainly on the other computer task). However, there is no way to confirm this suspicion. For increased task difficulty, future research should employ one complex task, rather than a dual task.

Another limitation was the length of the sustained attention task. On any task, performance drops off over time. It was originally assumed that 20 min would be an adequate length of time to observe this expected decline in performance. However, there was no evidence of decline in performance on this task. A possible explanation is that 20 min was not long enough for a decline in performance to occur. To observe the effects of glucose on a sustained task, the task should be of at least 40 min duration. This would ensure that the expected drop off in performance would occur.

The order in which participants were tested may have been a problem. It was easier to recruit participants for the younger age group, so most of the younger age group went through the experimental procedure earlier in the data collection period. Consequently, the majority of the older age group went through the experimental procedure later in the data collection period, when the researcher's techniques were more refined. However, it is unlikely that the younger age group were disadvantaged as they performed considerably better than the older age group on every measure.

Some major computer problems were experienced early in the course of this experiment. After 2 instances of the computer 'freezing' mid-task, which meant that the participant had to start the computerised task again, an escape route was added to the programme. Unfortunately, this would have disadvantaged those 2 participants. These participants' data should have been removed, and 2 new participants recruited. However, due to time constraints, this was not possible. Computer problems are inevitable. The only safeguard against problems like this is to expect problems, and to allocate enough 'emergency' time for them to be dealt with, a scenario that is not always possible when strict time limits are imposed on the research programme.

Reaction time tasks almost invariably involve a speed-accuracy trade-off. As reaction time (speed) increases, so does the number of errors made. This limitation means that reaction time results should always be interpreted with caution. In the present study, the number of errors made by participants on the reaction time measure was negligible. However, future research should consider different techniques in measuring reaction time. One technique is to only use correct responses. To do this, the number of errors would need to be proportionately decreased by practice, or in some other way. For instance, by making the task easier, or by introducing a motivation component (e.g., rewards for correct responses or punishment for incorrect responses). This is a common issue for any research on reaction time, and one that there is a substantial amount of literature on.

This present research lacked one important manipulation check. Some of the participants from the present study claimed that they could taste the difference between the glucose and placebo drinks. As described in the Method section, the drink ingredients and proportions used in the present study were the same as those piloted and used in Culligan's (2002) study. Although participants claimed to identify a difference between the 2 drinks, they did not necessarily know which drink contained the glucose. Thus, the impact of this limitation on the outcome of the present research is unknown. Future studies should ask participants to state which condition was glucose and which was placebo at the completion of the trials. A simple statistical test could be employed to find out if the percentage of correct choices was greater than one would expect by chance.

Another limitation of the present study was the mode of presentation that was used for the declarative memory task. For future research, it is recommended that the paragraphs be recorded on an audiotape. This would ensure that the reader's tone, intonations, and so forth were the same for each participant. Although the WMS manual does not specify that this be done, the consistency achieved by a recording would increase the reliability of the results.

All future research on glucose effects needs to consider the inclusion of natural history conditions. Further research involving natural history conditions will help to explain the effects of glucose on cognition, and also the limits of those effects. Future research on the different conditions in which glucose enhances cognition is necessary. For example, research comparing age groups, sex, body weight, task difficulty, and so on, could all help to clarify the influence of glucose on cognition. Also, more research on glucose and declarative memory is required to elucidate why Culligan (2002) and the present study obtained null results, when much of the previous research demonstrates a glucose effect on declarative memory tasks. Future research into the effects of glucose on sustained attention tasks would be of interest. In particular, further research is required to try and replicate the significant effects of glucose on LTO, but not on NTO, in the sustained attention task. If this result is replicated this would be a very important finding as it would strongly suggest the glucose (at least in older adults) might have a small benefit for speed of processing, but not for hand-eye co-ordination. Positive findings in this area could have implications for air traffic control and other areas that require high levels of vigilance.

Summary and Conclusions

The present study produced mostly non-significant results. Contrary to the majority of previous findings, declarative memory was not enhanced by the administration of glucose. Performance on the sustained attention task was also generally unaffected by the glucose drink, although its positive effect on the older participants for the LTO measure is of considerable interest.

The purpose of this study was to replicate and extend research by Fischer et al. (2001). Unfortunately, this study was unable to replicate Fischer and colleagues' findings. On the

other hand, the present results are generally supportive of previous research findings on the effects of glucose obtained in the Massey University laboratory (Culligan, 2002). It appears that the glucose effect is small. To detect this effect, studies must be carefully designed to reduce variability in the data and ensure that there is sufficient statistical power to detect small effects.

The present study was the first to analyse the effects of glucose over time. It is also the first to involve a natural history condition. The analysis of glucose over time on the sustained attention task produced one significant result. There was a significant interaction effect for period on the LTO measure of the sustained attention task. For the LTO measure, participants in the glucose condition performed consistently better than those in the placebo condition, but only in the older age group. This is a valuable finding that warrants further research.

The involvement of a natural history condition also provided some valuable findings. Although, there were no significant differences between the 3 conditions, the possibility of a placebo effect is evident from trends present in the results.

Previous research on glucose and cognition has produced inconsistent results. Unfortunately, the results of the present study have done little to clear up these inconsistencies. However, trends from the present study's results indicate that a placebo effect is a possible explanation for some of these inconsistencies. Given the likelihood that the glucose effect is small, it is imperative that future studies include a natural history group so that any placebo contribution to the glucose effect can be ascertained.

In conclusion, the present study has demonstrated that declarative memory and sustained attention are not always enhanced by glucose in younger or older adults. The one significant

outcome, involving only the older participants, suggests that some aspects of cognitive performance, other than memory, may be influenced by the intake of a small amount of glucose.

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APPENDICES

APPENDIX A

Information Sheet

The Effects of Glucose on Cognitive Performance

Information Sheet

My name is Kelly Richardson and I am carrying out this research to complete my Master of Arts degree at Massey University. I can be contacted at any time on [redacted] My supervisor for this research is Associate Professor John Podd. He can be contacted on **06 3505799 ext 2067**. This research is partially funded by Crop and Food Research.

This research aims to learn about the effects of glucose on the performance of cognitive tasks.

Volunteers are required to speak English, and also to be in good health. Potential volunteers will be excluded for the following reasons:

- Diabetes
- Hearing or visual impairment
- Any neurological, psychiatric or psychological disorders
- The use of any medications that could interfere with cognition, sensory-motor performance and/or digestion, or any anticoagulants
- Objection to supplying blood samples
- Any physical disorders that impair cognitive, sensory-motor or digestive functioning

Twenty-four participants will be recruited for this study. A within-subjects design will be employed, which means that all participants will experience each of the experimental conditions.

Participants will be required to perform an overnight fast before coming in for the experiment. Participants will then be required to consume a glucose drink, a placebo, or nothing. Then, participants will complete a paragraph recall (memory) task, and a computerized task assessing sustained attention and reaction time. Participant responses to the paragraph recall task will be audiotaped.

Blood will be collected, using a finger prick device (lancet), 5 times during the tasks. This finger prick is relatively painless. All precautions will be taken to minimize the risk of contamination.

Participants will need to undergo these procedures 3 times. Each session will take approximately 1 hour. Participants will also need to attend a 30-minute training session. Participants will be reimbursed for all time and travel expenses.

As a participant you have the following rights:

The right to:

- decline to participate
- decline to answer any particular question
- withdraw from the study at any time
- ask any questions about the study at any time during participation
- provide information on the understanding that your name will not be used unless you give permission to the researcher
- be given access to a summary of the research findings when the research is concluded

- ask for the audiotape to be turned off at any time during participation

Although any adverse physical or psychological risks are unlikely, support processes are available if necessary (e.g. doctor, counselor).

If you have any cultural or religious concerns regarding blood handling or any other issues associated with this study, please tick the appropriate box on the consent form.

This project has been reviewed and approved by the Massey University Human Ethics Committee, PN Protocol 03/66. If you have any concerns about the conduct of this research, please contact Professor Sylvia V. Rumball, Chair, Massey University Campus Human Ethics Committee: Palmerston North, telephone 06 350 5249, email S.V.Rumball@massey.ac.nz.

Please feel free to contact me, or my supervisor, if you have any questions regarding this research. Thank you.

Kelly Richardson

APPENDIX B

Consent Form

The Effects of Glucose on Cognitive Performance

Consent Form

This consent form will be held for a period of 5 years.

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree/do not agree to being audio taped.

I wish/do not wish to discuss cultural and/or religious concerns regarding this study.

I wish/do not wish to be provided with a summary of the results of this study when they are available.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: **Date:**

Full name (printed):

APPENDIX C

Biographical Questionnaire

The Effects of Glucose on Cognitive Performance

Participant Questionnaire

Name: Female/Male (circle one)

Age:

Is English your first language? Yes/No

Please indicate if you experience any of the following conditions:

- Diabetes
- Visual or hearing impairment
- Any neurological, psychiatric or psychological disorder
- Any physical disorder that impairs sensory-motor, cognitive or digestive functioning €

If you ticked any of the above boxes, please give further detail:

Do you take any medications that could interfere with sensory-motor, cognitive or digestive functioning? Yes/No

If yes, please give further detail: _____

_____

_____

_____

Do you have any objection to supplying blood samples? Yes/No

Do you have any cultural and/or religious concerns regarding blood handling that you would like us to address? Yes/No

If yes, please give further detail: _____

_____

_____

_____

Would you like to be provided with a summary of the results of this research when they are available? Yes/No

If yes, please provide an email or mailing address: _____

APPENDIX D

Instructions and Paragraphs for the Declarative Memory Task

Instructions

I am going to read you a little selection of about four or five lines. Listen carefully because when I am through I want you to tell me everything I read to you. Are you ready?

Now what did I read to you? Tell me everything and begin at the beginning.

Paragraph 1

Anna Thompson of South Boston, employed as a cook in a school cafeteria, reported at the police station that she had been held up on State Street the night before and robbed of fifty-six dollars. She had four small children, the rent was due, and they had not eaten for two days. The police, touched by the woman's story, took up a collection for her.

Paragraph 2

At 6:00 on Monday evening, Joe Garcia of San Francisco was watching television as he dressed to go out. A weather bulletin interrupted the program to warn that thunderstorms would move into the area within the next two to three hours and remain until morning. The announcer said the storm could bring hail and up to four inches of rain and cause the temperature to drop by fifteen degrees. Joe decided to stay home. He took off his coat and sat down to watch old movies.

Paragraph 3

The American liner, New York, struck a mine near Liverpool Monday evening. In spite of a blinding snowstorm and darkness, the sixty passengers, including eighteen women, were all rescued, though the boats were tossed about like corks in the heavy sea. They were brought into port the next day by a British steamer.

APPENDIX E

ANOVA Tables

Declarative Memory

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
drink	Sphericity Assumed	84.840	2	42.420	.275	.761
	Greenhouse-Geisser	84.840	1.875	45.253	.275	.747
	Huynh-Feldt	84.840	2.000	42.420	.275	.761
	Lower-bound	84.840	1.000	84.840	.275	.606
drink * agegroup	Sphericity Assumed	35.418	2	17.709	.115	.892
	Greenhouse-Geisser	35.418	1.875	18.892	.115	.880
	Huynh-Feldt	35.418	2.000	17.709	.115	.892
	Lower-bound	35.418	1.000	35.418	.115	.739
Error (drink)	Sphericity Assumed	5547.381	36	154.094		
	Greenhouse-Geisser	5547.381	33.746	164.386		
	Huynh-Feldt	5547.381	36.000	154.094		
	Lower-bound	5547.381	18.000	308.188		

Tests of Between-Subjects Effects

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	92557.230	1	92557.230	287.100	.000
agegroup	1889.987	1	1889.987	5.862	.026
Error	5802.961	18	322.387		

Total NTO

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
drink	Sphericity Assumed	240.528	2	120.264	.064	.938
	Greenhouse-Geisser	240.528	1.934	124.400	.064	.934
	Huynh-Feldt	240.528	2.000	120.264	.064	.938
	Lower-bound	240.528	1.000	240.528	.064	.803
drink * agegroup	Sphericity Assumed	3462.528	2	1731.264	.918	.407
	Greenhouse-Geisser	3462.528	1.934	1790.800	.918	.404
	Huynh-Feldt	3462.528	2.000	1731.264	.918	.407
	Lower-bound	3462.528	1.000	3462.528	.918	.348
Error (drink)	Sphericity Assumed	82990.278	44	1886.143		
	Greenhouse-Geisser	82990.278	42.537	1951.005		
	Huynh-Feldt	82990.278	44.000	1886.143		
	Lower-bound	82990.278	22.000	3772.285		

Tests of Between-Subjects Effects
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1499623.347	1	1499623.347	93.359	.000
agegroup	318269.014	1	318269.014	19.814	.000
Error	353385.306	22	16062.968		

NTO Across Periods

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent Parameter	Observed Power
DRINK	Sphericity Assumed	133.211	2	66.605	.160	.853	.009	.319	.073
	Greenhouse-Geisser	133.211	1.772	75.162	.160	.828	.009	.283	.071
	Huynh-Feldt	133.211	2.000	66.605	.160	.853	.009	.319	.073
	Lower-bound	133.211	1.000	133.211	.160	.694	.009	.160	.066
DRINK * AGE	Sphericity Assumed	201.548	2	100.774	.242	.787	.014	.483	.085
	Greenhouse-Geisser	201.548	1.772	113.720	.242	.760	.014	.428	.083
	Huynh-Feldt	201.548	2.000	100.774	.242	.787	.014	.483	.085
	Lower-bound	201.548	1.000	201.548	.242	.629	.014	.242	.075
Error (DRINK)	Sphericity Assumed	14177.186	34	416.976					
	Greenhouse-Geisser	14177.186	30.129	470.546					
	Huynh-Feldt	14177.186	34.000	416.976					
	Lower-bound	14177.186	17.000	833.952					
PERIOD	Sphericity Assumed	153.067	9	17.007	1.163	.322	.064	10.469	.560
	Greenhouse-Geisser	153.067	5.377	28.464	1.163	.333	.064	6.255	.412
	Huynh-Feldt	153.067	8.619	17.760	1.163	.324	.064	10.026	.546
	Lower-bound	153.067	1.000	153.067	1.163	.296	.064	1.163	.175
PERIOD * AGE	Sphericity Assumed	78.056	9	8.673	.593	.801	.034	5.339	.284
	Greenhouse-Geisser	78.056	5.377	14.515	.593	.717	.034	3.190	.215

	Huynh-Feldt	78.056	8.619	9.057	.593	.794	.034	5.113	.277
	Lower-bound	78.056	1.000	78.056	.593	.452	.034	.593	.112
Error (PERIOD)	Sphericity Assumed	2237.003	153	14.621					
	Greenhouse-Geisser	2237.003	91.417	24.470					
	Huynh-Feldt	2237.003	146.520	15.268					
	Lower-bound	2237.003	17.000	131.588					
DRINK * PERIOD	Sphericity Assumed	411.071	18	22.837	1.506	.086	.081	27.101	.910
	Greenhouse-Geisser	411.071	5.876	69.958	1.506	.185	.081	8.847	.554
	Huynh-Feldt	411.071	9.856	41.706	1.506	.142	.081	14.840	.729
	Lower-bound	411.071	1.000	411.071	1.506	.237	.081	1.506	.212
DRINK * PERIOD * AGE	Sphericity Assumed	295.155	18	16.397	1.081	.370	.060	19.459	.757
	Greenhouse-Geisser	295.155	5.876	50.231	1.081	.379	.060	6.352	.405
	Huynh-Feldt	295.155	9.856	29.945	1.081	.379	.060	10.655	.551
	Lower-bound	295.155	1.000	295.155	1.081	.313	.060	1.081	.166
Error (DRINK* PERIOD)	Sphericity Assumed	4641.375	306	15.168					
	Greenhouse-Geisser	4641.375	99.891	46.464					
	Huynh-Feldt	4641.375	167.559	27.700					
	Lower-bound	4641.375	17.000	273.022					

Tests of Between-Subjects Effects
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent Parameter	Observed Power
Intercept	112024.552	1	112024.552	79.849	.000	.824	79.849	1.000
AGE	19447.773	1	19447.773	13.862	.002	.449	13.862	.939
Error	23850.220	17	1402.954					

LTO

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent Parameter	Observed Power
DRINK	Sphericity Assumed	3681737.312	2	1840868.656	1.390	.262	.072	2.780	.279
	Greenhouse-Geisser	3681737.312	1.159	3176003.156	1.390	.257	.072	1.611	.214
	Huynh-Feldt	3681737.312	1.258	2926792.152	1.390	.259	.072	1.748	.222
	Lower-bound	3681737.312	1.000	3681737.312	1.390	.254	.072	1.390	.201
DRINK * AGE	Sphericity Assumed	4255284.212	2	2127642.106	1.606	.215	.082	3.213	.317
	Greenhouse-Geisser	4255284.212	1.159	3670766.897	1.606	.222	.082	1.862	.240
	Huynh-Feldt	4255284.212	1.258	3382733.502	1.606	.222	.082	2.021	.250
	Lower-bound	4255284.212	1.000	4255284.212	1.606	.221	.082	1.606	.225
Error (DRINK)	Sphericity Assumed	4767856.625	36	1324404.295					
	Greenhouse-Geisser	4767856.625	20.866	2284961.780					
	Huynh-Feldt	4767856.625	22.643	2105667.116					
	Lower-bound	4767856.625	18.000	2648809.590					
PERIOD	Sphericity Assumed	2039325.967	9	2265916.996	5.683	.000	.240	51.149	1.000

	Greenhouse-Geisser	2039325 2.967	1.601	1273950 3.280	5.683	.012	.240	9.098	.765
	Huynh-Feldt	2039325 2.967	1.830	1114191 7.017	5.683	.009	.240	10.402	.807
	Lower-bound	2039325 2.967	1.000	2039325 2.967	5.683	.028	.240	5.683	.616
PERIOD * AGE	Sphericity Assumed	1668636 9.673	9	1854041 .075	4.650	.000	.205	41.851	.999
	Greenhouse-Geisser	1668636 9.673	1.601	1042384 2.706	4.650	.024	.205	7.444	.675
	Huynh-Feldt	1668636 9.673	1.830	9116649 .831	4.650	.019	.205	8.511	.719
	Lower-bound	1668636 9.673	1.000	1668636 9.673	4.650	.045	.205	4.650	.532
Error (PERIOD)	Sphericity Assumed	6459036 0.967	162	398705. 932					
	Greenhouse-Geisser	6459036 0.967	28.814	2241615 .882					
	Huynh-Feldt	6459036 0.967	32.946	1960508 .004					
	Lower-bound	6459036 0.967	18.000	3588353 .387					
DRINK * PERIOD	Sphericity Assumed	1174122 4.172	18	652290. 232	1.497	.089	.077	26.944	.909
	Greenhouse-Geisser	1174122 4.172	1.618	7257549 .105	1.497	.240	.077	2.422	.267
	Huynh-Feldt	1174122 4.172	1.853	6336402 .107	1.497	.239	.077	2.774	.286
	Lower-bound	1174122 4.172	1.000	1174122 4.172	1.497	.237	.077	1.497	.212
DRINK * PERIOD * AGE	Sphericity Assumed	1262677 9.005	18	701487. 722	1.610	.056	.082	28.976	.932
	Greenhouse-Geisser	1262677 9.005	1.618	7804933 .057	1.610	.219	.082	2.604	.284
	Huynh-Feldt	1262677 9.005	1.853	6814310 .664	1.610	.216	.082	2.983	.305
	Lower-bound	1262677 9.005	1.000	1262677 9.005	1.610	.221	.082	1.610	.225
Error (DRINK* PERIOD)	Sphericity Assumed	1411873 71.125	324	435763. 491					
	Greenhouse-Geisser	1411873 71.125	29.120	4848416 .826					

	Huynh-Feldt	1411873 71.125	33.354	4233043 .159
	Lower-bound	1411873 71.125	18.000	7843742 .840

Tests of Between-Subjects Effects
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent Parameter	Observed Power
Intercept	660387204.000	1	660387204.000	46.543	.000	.721	46.543	1.000
AGE	199159833.760	1	199159833.760	14.036	.001	.438	14.036	.943
Error	255400034.533	18	14188890.807					

RT

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent Parameter	Observed Power
DRINK	Sphericity Assumed	898755.003	2	449377.502	1.676	.202	.090	3.353	.328
	Greenhouse-Geisser	898755.003	1.580	568918.794	1.676	.209	.090	2.648	.289
	Huynh-Feldt	898755.003	1.817	494692.233	1.676	.205	.090	3.046	.312
	Lower-bound	898755.003	1.000	898755.003	1.676	.213	.090	1.676	.231
DRINK * AGE	Sphericity Assumed	593695.452	2	296847.726	1.107	.342	.061	2.215	.228
	Greenhouse-Geisser	593695.452	1.580	375813.764	1.107	.332	.061	1.749	.204
	Huynh-Feldt	593695.452	1.817	326781.523	1.107	.338	.061	2.012	.218
	Lower-bound	593695.452	1.000	593695.452	1.107	.307	.061	1.107	.169
Error (DRINK)	Sphericity Assumed	9113750.281	34	268051.479					
	Greenhouse-Geisser	9113750.281	26.856	339357.274					
	Huynh-Feldt	9113750.281	30.886	295081.494					
	Lower-bound	9113750.281	17.000	536102.958					

PERIOD	Sphericity Assumed	250654.198	9	27850.466	1.166	.321	.064	10.491	.561
	Greenhouse-Geisser	250654.198	3.176	78924.245	1.166	.333	.064	3.702	.304
	Huynh-Feldt	250654.198	4.220	59392.645	1.166	.334	.064	4.919	.358
	Lower-bound	250654.198	1.000	250654.198	1.166	.295	.064	1.166	.175
PERIOD * AGE	Sphericity Assumed	206478.352	9	22942.039	.960	.475	.053	8.642	.465
	Greenhouse-Geisser	206478.352	3.176	65014.463	.960	.422	.053	3.050	.255
	Huynh-Feldt	206478.352	4.220	48925.155	.960	.438	.053	4.052	.297
	Lower-bound	206478.352	1.000	206478.352	.960	.341	.053	.960	.152
Error (PERIOD)	Sphericity Assumed	3655539.634	153	23892.416					
	Greenhouse-Geisser	3655539.634	53.990	67707.695					
	Huynh-Feldt	3655539.634	71.745	50951.885					
	Lower-bound	3655539.634	17.000	215031.743					
DRINK * PERIOD	Sphericity Assumed	499706.578	18	27761.477	1.111	.340	.061	20.006	.772
	Greenhouse-Geisser	499706.578	3.798	131571.414	1.111	.358	.061	4.221	.322
	Huynh-Feldt	499706.578	5.314	94027.464	1.111	.361	.061	5.907	.392
	Lower-bound	499706.578	1.000	499706.578	1.111	.307	.061	1.111	.169
DRINK * PERIOD * AGE	Sphericity Assumed	687415.181	18	38189.732	1.529	.078	.083	27.521	.915
	Greenhouse-Geisser	687415.181	3.798	180994.590	1.529	.207	.083	5.807	.435
	Huynh-Feldt	687415.181	5.314	129347.720	1.529	.185	.083	8.126	.530
	Lower-bound	687415.181	1.000	687415.181	1.529	.233	.083	1.529	.215
Error (DRINK* PERIOD	Sphericity Assume	7643246.454	306	24977.930					

Greenhouse-Geisser	7643246.454	64.566	118379.204
Huynh-Feldt	7643246.454	90.346	84599.656
Lower-bound	7643246.454	17.000	449602.733

Tests of Between-Subjects Effects

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent Parameter	Observed Power
Intercept	285798468.900	1	285798468.900	472.371	.000	.965	472.371	1.000
AGE	551621.377	1	551621.377	.912	.353	.051	.912	.147
Error	10285514.847	17	605030.285					