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Blood glucose level and the consolidation of learning

It is not uncommon for students to miss breakfast and thus attend classes in a state of mild fasting. An unpublished study at the University of Wolverhampton showed that students who did consume breakfast ingested a meal that, on average, provided considerably less than 300kCals. This is of considerable importance for the learning process since food, especially carbohydrate, is the only source of glucose and this is needed for metabolic processes.

Crucially, glucose is normally the only 'fuel' used by the brain. If glucose supply is compromised then cognitive processes such as memory and comprehension will be undermined. At Wolverhampton we have been studying the effects of modifying blood glucose levels on the learning process for 10 years. This article reports a study that attempts to optimise the consolidation of learning by moderately raising blood glucose immediately after study.

Glucose and Learning

An earlier study[1] showed that a glucose drink given to 'A' level students who had fasted overnight led to better listening comprehension than a similar group who received a saccharine sweetened drink. The elevation of blood glucose level seems to increase the functionally available memory space. It is therefore of considerable educational interest and has clear practical implications. The current study builds on this earlier work.

Glucose is the only sugar that we 'burn' for energy. When we consume other carbohydrates, whether complex carbohydrates, for example starch, or simple sugars, for example sucrose (commercial granulated sugar), these are broken down by enzymes in saliva and the gut into glucose and subsequently absorbed across the gut wall into the bloodstream. It is important to maintain the blood levels of glucose at around 5 mmol/l and, in non-diabetic individuals with good blood glucose control, this is achieved by the release of insulin when levels rise above 5 mmol/l. The glucose available in the blood is used to fuel metabolic processes. Crucially, the brain cannot store glucose so it relies entirely on glucose provided by the bloodstream. Thus if one measures blood glucose with a glucometer using a single drop of blood from the finger then the reading reflects not just the glucose available in the finger but also that currently available in the brain. One reason why memory is enhanced, in some situations, by a glucose drink is likely to be due simply to the brain having more fuel to optimise memory functioning. However glucose also has toxic effects, so massive ingestion of glucose, or carbohydrate rich food, would not produce a large increase in memory performance. Hyperglycaemia (>7 mmol/l blood glucose[2]) tends to produce drowsiness[3] and would have long term health implications. This means that we may be able to produce modest increases in memory performance by inducing small increases in blood glucose level. As noted earlier, it is fairly common for students to begin the day initially mildly hypoglycaemic and this is associated with poorer memory performance[1].

In the present study a memory task that realistically represents a classroom situation was used. The study was incorporated into

workshops on "Brain and Nutrition" provided for second year undergraduates at Wolverhampton University. Students watched a 55 minute documentary on Elvis Presley's eating habits as a case study in eating pathology and, sometime later, they filled out a multiple choice test on the content of the documentary. In a recent study,[4] participants, in one condition, received glucose after being presented with a list of 20 words to memorise but before recall was required. The results showed that glucose could still enhance recall suggesting that glucose was not simply important for creating memories, it was also important for consolidating them, that is, glucose is important for making memories more permanent and thus reducing forgetting.

In this study it was hypothesised that more material would be recalled by a group of students receiving a glucose drink after the presentation than a group receiving a saccharine drink after the presentation. Blood glucose level was measured at the beginning of the study so actual baseline measures were available for each individual.

The Study

120 undergraduates, aged 19 - 32, volunteered to participate in this study as part of a series of workshops on the brain and nutrition. Attendance was mandatory for course credit but students not wishing to actively participate were able to gain credit by observing the experiment. Individuals were excluded from active participation if they suffered from diabetes, haemophilia or any other serious metabolic disorder. There were 84 female and 36 male participants who provided usable data. All participants signed informed consent forms to indicate that they understood the experimental procedure and, in particular, the briefing on the Wolverhampton safe blood sampling protocol. Before signing they were aware that this study had been vetted by the Wolverhampton University Science Ethics Committee.

There were two different conditions in the study. Half of the students imbibed a glass of orange juice containing glucose and the remainder had an orange drink containing saccharine instead of glucose. The students in the glucose condition received a drink consisting of 50 grams of glucose in 250ml of water plus 40ml sugar free 'Robinsons' Whole Orange Quash and 10ml of lemon juice (to reduce the sweetness). Those students who were assigned to the saccharine condition drank orange juice that was identical except that 2 grams of 'Sweetex' replaced the glucose. A pilot study at the University of Wolverhampton indicated that students could not distinguish between these two drinks.

Blood glucose level was tested using BM-Test 1-44 blood glucose test strips, following the manufacturers procedure and then measured with Prestige Medical Healthcare Ltd. HC1 digital Blood Glucometers. The average of two measures was recorded at each testing.

The study was run over three days and each session commenced at 10 a.m. with a briefing on the study. Each student attended only one session. The briefing did not identify the drink to be consumed. Students were told that the study used both glucose and saccharine in the drinks and that they should abstain from drinking if they were likely to be adversely affected by any of the constituents. After the briefing informed consent forms were filled out and then students went to cubicles outside of the main laboratory area, at 10.30 am, where they were shown how to sample their own blood by trained demonstrators. In all cases students were the only person who came into contact with their blood and they were required to discard all disposable materials themselves (lancets, test strips, antiseptic swabs etc.) into sharps containers for later incineration. This results in a minimal biological hazard from body fluids. Any blood droplets not captured on test strips or

swabs were covered in powdered bleach by the demonstrator. After applying their blood sample to two glucometers and recording the reading participants returned to their seats.

All participants then watched a 55 minute recording of "The Burger and the King", a BBC documentary shown in 1995. This contained material directly relevant to the course they were taking and, since it had not been broadcast for more than 10 years it was unlikely to be familiar to the participants. Following this presentation, at 12.00 pm, students consumed the drink on the bench in front of them. They were then allowed to take a break of 20 minutes during which they were not to eat anything or consume any drinks other than bottled water. When they returned they had their blood sampled again and then they returned to their bench and filled out a brief questionnaire that elicited information about what they had had for breakfast that morning. Following this, at 12.40 pm, they completed a multiple choice test on the contents of the documentary. There were 10 questions with five answer options, with only one correct answer to each question so chance level performance was 20%. The study finished at 1 pm and students were debriefed two weeks later when the data had been analysed. Debriefing was deferred so that groups attending the second and third workshops could not learn the purpose of the study from members of the first group. The timings of the various stages of the first session were noted and sessions two and three stages were executed within a few minutes of the session one timings.

Results

The blood sugar data were analysed statistically using two-way analysis of variance. There was a significant statistical interaction and this showed that there was no significant change in the blood glucose level of the saccharine group but the glucose drink resulted in a significant increase in blood glucose in the glucose drinking group ($F(2,118)=118.14$ $p<0.0001$). The means and standard deviations, together with the results of the memory test are shown in Table 1. The memory data was analysed with an independent samples t-test and this showed that memory was significantly better for the glucose group ($t(118)=2.76$, $p<0.01$). To summarise, the results show that the glucose drink increased blood glucose level, the saccharine drink did not and the group with elevated blood glucose had better memory recall.

Table 1: Means and standard deviations (in brackets) for % correct responses on a multiple choice test and blood sugar levels (in mmol/l) for two groups, one consuming a glucose rich drink and the other consuming a drink with saccharine as a sweetener.

Condition	Multiple choice score	First blood sugar reading mm/l	Second blood sugar reading mm/l
Glucose Group n=60	71.5 (16.2)	4.84 (0.82)	7.22 (1.57)
Saccharine Group n=60	62.2 (13.2)	4.85 (0.83)	4.72 (0.84)

The data from the breakfast questionnaire were examined informally simply to gain some background into the nutritional habits of the sample. It is possible to calculate very roughly the calorific intake of the student breakfast from the information provided. Several students had abstained from breakfast but the majority had consumed ~200 kCalories, mainly as sugared beverages and toast. Several probably consumed closer to 300 kCalories by adding undisclosed amounts of jam or peanut butter to their toast. This had no strikingly obvious effect on their initial blood glucose reading but breakfast was probably consumed at least two hours prior to blood sugar testing.

Conclusions

■ This study suggests that even if breakfast is missed it is still worthwhile to

elevate blood glucose level after instruction. However this is still very much a 'damage limitation' exercise.

■ High blood glucose levels are toxic. Blood glucose level should only be raised modestly, and not greater than ~ 7 mmol/l for any length of time.

■ Ideally students should have a nutritious breakfast before attending classes. It also follows that since glucose is rapidly removed from the bloodstream, especially in the young, that lunch is also an important meal otherwise the mild hypoglycaemia commonly found in the morning would reoccur in the afternoon. Sünram-Lea and her colleagues[5] have shown that verbal long-term memory is improved in a group receiving lunchtime glucose compared to a group abstaining from any form of lunch. One might also expect, although this remains to be tested, that a mid-afternoon snack might ameliorate the impairment to learning arising from missing lunch.

■ It is likely that the major effect of glucose administration is to provide sufficient 'fuel' for the metabolic activity associated with learning. Provided there is sufficient glucose in the bloodstream we would not expect further enhancement with even more glucose. In this study 50 grams of glucose improved consolidation without producing undesirable blood glucose levels. However glucose solution has a glycaemic index (G.I.) of 100. Indeed it is the standard to which other carbohydrate sources are compared. The G.I. measures how rapidly 50 grams of carbohydrate from a food raises blood sugar levels compared to 50 grams of glucose[5]. Low G.I. foods gradually release their glucose into the bloodstream and this is desirable as it tends to maintain healthy blood glucose levels without producing peaks and troughs, that is, without large increases in blood sugar levels followed by sudden drops due to insulin release. Thus whereas drinking a sweetened soft drink, for example a large (16 oz) cola, will provide ~ 50 grams of glucose and rapidly reverse mild hypoglycaemia a more healthy approach would be to obtain the 50 grams of glucose, before studying and by slower absorption, by consuming low or medium G.I. meals (for example, porridge).

■ This study shows that memory can be enhanced at the consolidation phase by consuming glucose provided blood sugar level was initially at 5mmol/l or less. However this practise is not recommended as a study option except when circumstances have prevented the student from partaking of a nutritious meal before study commences. Rather, taken together with other studies examining the effects of raising blood glucose on memory, these findings show that carbohydrate is an important factor in the learning experience. Low blood glucose impairs the initial assimilation of study material and, if the condition persists, subsequent consolidation is also compromised. A low or medium G.I. meal some considerable time, perhaps 1 to 1.5 hours, before attending classes could circumvent an additional burden on the student engaged in challenging study.

References

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