Article 16

Drinking Glucose Improves Listening Span in Students Who Miss Breakfast

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ABSTRACT. Low blood sugar level resulting from fasting has been shown to reduce performance on a number of cognitive tasks. In this study, 80 nondiabetic A-level students missed breakfast. They completed a version of Daneman and Carpenter's *Listening Span Test* at 9.00 A.M. Half were then given a drink containing glucose, while the other half received a saccharine drink matched for taste. After 20 minutes, both groups completed another form of the *Listening Span Test*. A subset of the sample had their blood glucose levels determined immediately before the drink and again before the second application of the test. Blood glucose levels did not change, but listening span performance significantly improved after a glucose drink, yet not after a saccharine drink. It is concluded that missing breakfast does not seriously affect blood sugar levels in healthy young students, but listening span performance, which is a good predictor of listening comprehension, is improved when fasting individuals imbibe a glucose-rich drink, although not when a saccharine drink is drunk. Ideally students should eat breakfast, but if this is omitted, then a glucose snack or drink before the first class may reverse any adverse effects.

Failure to eat breakfast before commencing a day of study is probably a fairly common occurrence. Although students may "self-medicate" by drinking sugar-laden drinks during the break between classes, it is likely that many young scholars attend a 9:00 A.M. class without having taken in a significant number of calories since the previous day. This study addresses the consequences of this for listening comprehension by examining the effects of a glucose drink on performance. It addresses the possibility that a "snack," consisting of glucose-rich material, may ameliorate any adverse effects of short-term fasting.

In healthy young individuals, blood glucose levels are maintained at around 5 mmol/l. This control is attained via a negative feedback loop. Insulin is released from the pancreas when blood sugar begins to rise above 5 mmol/l, and it results in glucose being removed from the circulation and immobilized, as glycogen, in the liver and in muscles. When blood sugar levels drop much below 5 mmol/l, the pancreas releases glucagon that releases glycogen from the liver. Glycogen is broken down into glucose and released into the bloodstream, increasing blood sugar until insulin release is triggered. In fact, insulin and glucagon are mutually inhibiting, so deviations from the "set point" for blood sugar occur largely because of absorption of glucose, mainly from the gut, and this is then rapidly regulated. Thus, even in early starvation, blood sugar is maintained because glycogen can be mobilized. Tight control of blood sugar is essential because the brain uses glucose as its "fuel" but it cannot store it—brain processes rely on glucose delivered by the bloodstream.

It is clear that blood glucose level is crucial to brain metabolism. Positron emission tomography studies, which can directly quantify the use of radioactively labeled glucose in the brain, show that different brain areas "light up" depending on the cognitive task being performed (Raichle, 1998). Nevertheless, a clear picture of the relationship between blood sugar level and cognitive capacity has not emerged. For example, Benton and Sargent (1992) found that memory for spatial material and lists of words was better after eating breakfast. However, although Lapp (1981) also found that lists of words were better recalled when blood sugar was high, Azari (1991) found no improvement. Benton and Sargent suggest that one generality that can be made is that tasks that require the participant to remember new information may be sensitive to consumption of breakfast. If this contention is valid, then this has clear implications for the efficiency of study.

Short-term, or working, memory capacity has been implicated in most intellectual tasks (see Baddeley, 1997, for a detailed account of this), and in particular, deficiencies in reading ability and comprehension, especially when listening, have often been associated with reduced working memory capacity (Gathercole and Baddeley, 1993). It is hardly surprising, then, that a test designed by Daneman and Carpenter (1980) to measure individual differences in working memory capacity has considerable predictive power with respect to standards of comprehension (Gathercole and Baddeley, 1993; King and Just, 1991). However, despite its usefulness as a psychometric instrument, Waters and Caplan (1996) have argued that although the Daneman and Carpenter (1980) tasks measure several components of working memory, they do not allow the individual components to be isolated, that is, the measures cannot separate comprehension from memory retention. Thus, a fine-grained analysis of sub-components is not possible with this instrument. Notwithstanding this, the test remains useful as a slightly "blunt" instrument with considerable predictive power.

In this study, we employ the *Listening Span Test* of Daneman and Carpenter (1980) as oral presentation of verbal material is still a predominant mode of delivery in the educational setting. Although Waters and Caplan (1996) did not examine this version of the task, it is likely that the same caveats apply. The *Listening Span Test* provides a measure of verbal memory capacity for *spoken* material, presented in sentences, with comprehension required. It is formally equivalent to the *written* reading comprehension test and addresses a fundamental aspect of the learning situation, the ability to process lecture material, and, thus, provides an educationally significant measure.

It is predicted that listening span will be sensitive to glucose consumption. This experiment compares two groups of A-level students who have fasted overnight and then twice completed the listening span task with a glucose or saccharine-laden drink being consumed between the two tests. Specifically, it is predicted that students who have fasted overnight will improve on this task after receiving a glucose-rich drink, whereas an almost calorie-free drink will not improve performance after fasting.

Method

Participants

Eighty A-level students from two colleges in the West Midlands participated in this study: 44 were male and 36 were female. The mean age was 21.15 years (s.d. = 4.35). None of these participants was under the age of 17, and none suffered from diabetes mellitus or had a known family history of diabetes mellitus. All had English as a first language.

Procedure

Students at two colleges in the West Midlands were approached, during classes, with a request that they volunteer to take part in a study of the effects of missing breakfast on intellectual performance. Those who were willing to participate signed informed consent forms, which included consenting to providing blood samples. All participants believed that they might have to give a blood sample to verify their abstinence. This strategy was used to ensure honesty of report when questioned about compliance with the fasting instructions.

Students were briefed on the day before testing and advised that they must not eat anything after midnight and must only drink water. No non-fasting group was included, as standardized calorie intake could not be meaningfully imposed because of differences in body weight, choice of food items consumed, etc. Clearly, there are likely to be individual differences in physiology within a fasting sample, but these should be minimized by using a young sample (who have very efficient blood sugar control, which deteriorates with age). Each participant was requested to report to a specified room for group testing at 9:00 a.m. Groups were never larger than 10, and several assistants ran sessions concurrently in a series of rooms within a particular college. Participants confirmed that they had fasted in the manner requested and were then randomly assigned to either the glucose or placebo group (they were not aware that there was a distinction) within a room.

They were administered a version of the Daneman–Carpenter (1980) *Listening Span Test*, which requires the student to listen to a series of sentences presented via a tape recorder. On response sheets provided, students recorded whether the proposition in each sentence was true or false. After a series of sentences had been presented, a different voice on the tape requested "recall." The students were then required to write down, in forward serial order, the last word in each sentence they had heard. For example, the sequence: (1) "Karl Marx was an Irish composer"; (2) "Tony Blair is a politician" would require "false," "true" to be ticked and "composer, politician" to be written on the recall sheet. The number of sentences in a sequence was incremented by one every two sequences, with the result that the longest sequence of sentences from which a student could recall all the last words in the order presented provided a measure of their listening span.

The decisions about the propositions were not scored for analysis; they were required to ensure that students actively listened to the whole of each sentence. (It was decided, before the study commenced, that students scoring less than 90 percent would be excluded from the analysis as they may have sacrificed comprehension for memory performance.) The study began with several practice and demonstration trials followed by trials with, initially, two sentences. The longest trials were six sentences. Two sets of trials were prepared for the study. Half the students in each condition experienced version 1 first, and the remainder experienced version 2 first. All sentences had a spoken duration of 2–2.5 seconds.

After completion of the *Listening Span Test*, there was an interval of 20 minutes. Students were given a 300 ml glass of orange juice to drink at the beginning of this interval, and they were requested to drink it rapidly. The students in the glucose condition received a drink consisting of 50 g glucose in 250 ml of water plus 40 ml sugar-free Robinson's "Whole-orange quash" and 10 ml of lemon juice (to reduce the sweetness). Those students who were assigned to the placebo condition drank orange juice that was identical, except that 2 g of "Sweetex" replaced the glucose. A pilot

Table 1
Means and Standard Deviations (in Parentheses) for Scores on the Daneman and Carpenter *Listening Span Test* Before and After Either a Glucose-Rich Drink or Drink with Saccharine Substituted for Glucose (Maximum Score Possible, 6; $n = 80$)

	Listening span before drink	Listening span after drink
Group receiving a glucose drink ($n = 40$)	2.4 (0.7)	3.1*(0.7)
Group receiving a saccharine drink ($n = 40$)	2.5 (0.7)	2.6 (0.6)

study at the University of Wolverhampton indicated that students could not distinguish between these two drinks.

During the 20-min interval between tests, the experimenters engaged in a question-and-answer session with the students about studying at the university. At the end of this time, a different version of the *Listening Span Test* was administered. Following this, the purpose of the study was explained and all students were advised to eat before attending their first class of the day.

The study was carried out in the classrooms that students studied in to maximize the realistic nature of the environment. Unfortunately, such environments are ill-suited to carrying out biologically hazardous procedures. The taking of blood samples within classrooms was deemed to be a biologically hazardous procedure by the University of Wolverhampton safety committee, with the result that restrictions were placed on the procedure, and only one room was designated for blood sampling. A clinically trained member of staff was present throughout sampling and handled disposal of sharps and other blood-contaminated material. As a result of this, blood samples were taken only from 10 participants (five from the placebo, and five from the glucose group). These participants provided three blood samples prior to ingestion of the drink and three further samples 20 min later, just prior to the second administration of the *Listening Span Test.* Blood glucose level was tested using BM–Test 1–44 blood glucose test strips, following the manufacturer's procedure and then measured with a Prestige Medical Healthcare Ltd. HC1 digital Blood Glucometer. The average of the three measures was recorded at each testing. It should be stressed that the selection of students to give blood samples was based purely on the room attended. All participants in the study had consented to provide blood prior to volunteering for the study.

Results

Blood Glucose Levels

Before administration of the drink, both groups who had their blood glucose levels measured had blood glucose levels of 4.60 mmol/l (glucose group s.d. = 0.16 and placebo group s.d. = 0.14). Twenty min after administration of drinks, the glucose group had a blood sugar level of 4.68 mmol/l (s.d. = 0.17, not significantly different from the first administration—$t(4) = 2.24$, $p > 0.05$), and the placebo group had a blood sugar level of 4.62 mmol/l (s.d. = 0.15, $t(4) = 0.01$, $p > 0.05$—no significant change). Thus, blood glucose levels were not significantly changed within 20 min by administration of a glucose-rich drink, and they remained at physiologically acceptable levels throughout the study. The two groups did not significantly differ in blood sugar levels across the study.

Listening Span Test

All participants scored at least 90 percent correct on the true/false decisions, so none was excluded from the analysis. The listening span data were subjected to a two-way mixed-design analysis of variance with Group (glucose/placebo) as the between-subject factor and Test (first test vs. second test) as the within-subject factor. There was no main effect of group ($F(1,78) = 2.62$, $p > 0.05$), but performance was significantly better after consuming the drink ($F(1,78) = 28.15$, $p < 0.001$). This effect was modified by an interaction ($F(1,78) = 17.38$, $p < 0.001$). Simple effects analysis (Kirk, 1968) revealed no performance differences before the drink was consumed ($p > 0.05$), but a large improvement in the glucose group after receiving the drink ($p < 0.01$). The means and standard deviations are shown in Table 1.

In summary, there were no reliable changes in blood glucose level within 20 min of receiving a drink containing glucose. However, performance on the Daneman–Carpenter *Listening Span Test* significantly improved in the group that had received a glucose drink but not in the group that received the saccharine drink. These two groups did not differ in their listening span performance before receiving the drink.

Discussion

These data show a modest increase—about a half sentence, on average—in listening span. If this recall of a half-item simply represented recalling an additional half-word, then, in practical terms, the increase would be trivial. Clearly, however, considerable working memory capacity is required. One might expect A-level students to recall seven or more items (Miller, 1956), but only three are recalled in the optimal condition. For simple word recall, this level of performance would be pathological. However, an average of a half-word recall improvement on the *Listening Span Test* represents a considerably larger increase in available capacity. It would be more accurate, given the nature of the test, to view this increase as being better represented as about a half-sentence increment in retention. Such an increase would allow comprehension of sentences with more clauses. Evidently, then, a half-item increment constitutes a useful improvement in listening comprehension/memory capacity and may lead to better comprehension of complex, educationally relevant material.

The literature suggests that this improvement occurs because blood sugar levels are elevated, and this glucose is available as "brain fuel." The failure to find any significant change in blood sugar level but a sugar-administration-related improvement in performance suggests a more complex relationship. One can only speculate on what this might be, and it should be borne in mind that the trend is in the right direction and might be more marked in a study with greater statistical power. One possible explanation is that reduced glucose availability results in release of stored glycogen to compensate and that this has physiological costs that impair cognitive processing. For example, neurotransmitter systems may be very sensitive to the pulses of glucose that they received. 5-HT (a.k.a. serotonin—an important transmitter in the brain) release, for example, is modified by glucose levels (Wurtman and Wurtman, 1986). Absorption of glucose from the gut may maintain levels more smoothly than the "crisis" release from the liver when levels suddenly start to fall.

Whatever the mechanism by which glucose ameliorates fasting effects, the rapidity with which it improves performance, without creating any hazard, suggests that most students can be advised to consume a convenient form of glucose if they have missed breakfast. One caveat, derived from Thayer (1989), is that "sugar-snacking" can rebound. It appears to be energizing initially but induces later fatigue. This is unlikely to occur following fasting. However, it would be preferable for students to eat a nutritious breakfast with abstinence from sugar snacks *unless* the student has missed breakfast.

References

Azari, N. P. (1991). Effects of glucose on memory processing in young adults, *Psychopharmacology, 105*, 521–4.

Baddeley, A. D. (1997). *Human memory: Theory and practice.* (2nd ed.). Hove: Psychology Press.

Benton, D., & Sargent, J. (1992). Breakfast, blood glucose and memory, *Biological Psychology, 24*, 95–100.

Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading, *Journal of Verbal Learning and Verbal Memory, 19*, 450–66.

Gathercole, S. E., & Baddeley, A. D. (1993). *Working memory and language.* Hove: Lawrence Erlbaum.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory, *Journal of Memory and Language, 30*, 580–602.

Kirk, R. E. (1968). *Experimental design: Procedures for the behavioural sciences.* Belmont, Calif.: Brooks/Cole.

Lapp, J. E. (1981). Effects of glycaemic alterations and noun imagery on the learning of paired associates, *Journal of Learning Disorders, 14*, 35–8.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information, *Psychological Review, 63*, 81–97.

Raichle, M. E. (1998). Behind the scenes of functional brain imaging: A historical and physiological perspective, *Proceedings of the National Academy of Science, USA, 95*, 765–72.

Thayer, R. E. (1989). *The biopsychology of mood and arousal.* Oxford: Oxford University Press.

Waters, G. S., & Caplan, D. (1996). The measurement of verbal working memory capacity and its relation to reading comprehension, *Quarterly Journal of Experimental Psychology, 49A*, 51–79.

Wurtman, R. J., & Wurtman, J. J. (1986). *Nutrition and the brain: Food constituents affecting normal and abnormal behaviours.* New York: Ravens, Vol. 7.

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Exercise for Article 16

Factual Questions

1. Does the *Listening Span Test* present sentences *or* does it present isolated words?

2. Was a nonfasting control group (i.e., a group that did not fast the night before) included in this study?

3. Were the participants randomly assigned to the two groups?

4. Blood samples were taken from how many participants in the placebo group?

5. What was the mean score for the glucose group after they received the drink (i.e., what was the posttest score for the glucose group)?

6. Do the researchers characterize the increase in listening span for the glucose group as "very large"?

7. Do the researchers interpret these results to suggest that students should be advised to eat sugar snacks in the morning?

Questions for Discussion

8. Half the participants were administered version 1 of the *Listening Span Test* first, and the other half were administered version 2 first. This is an example of what researchers call "counterbalancing." Speculate on why the researchers counterbalanced the two versions of the test.

9. This research report is identified as an example of "true experimental research" in the table of contents of this book. Do you agree with the classification? Why? Why not?

10. The blood tests failed to reveal elevated blood

sugar levels in the glucose group. In your opinion, does this fact make it difficult to interpret the results of this study? Does it decrease your confidence in the results of this study? Explain. (See lines 276–293.)

11. In your opinion, does this study provide definitive evidence that students should eat breakfast in the morning? Explain.

12. To what population(s) of students, if any, would you be willing to generalize the results of this study?

Quality Ratings

Directions: Indicate your level of agreement with each of the following statements by circling a number from 5 for strongly agree (SA) to 1 for strongly disagree (SD). If you believe an item is not applicable to this research article, leave it blank. Be prepared to explain your ratings.

A. The introduction establishes the importance of the study.
SA 5 4 3 2 1 SD

B. The literature review establishes the context for the study.
SA 5 4 3 2 1 SD

C. The research purpose, question, or hypothesis is clearly stated.
SA 5 4 3 2 1 SD

D. The method of sampling is sound.
SA 5 4 3 2 1 SD

E. Relevant demographics (for example, age, gender, and ethnicity) are described.
SA 5 4 3 2 1 SD

F. Measurement procedures are adequate.
SA 5 4 3 2 1 SD

G. All procedures have been described in sufficient detail to permit a replication of the study.
SA 5 4 3 2 1 SD

H. The participants have been adequately protected from potential harm.
SA 5 4 3 2 1 SD

I. The results are clearly described.
SA 5 4 3 2 1 SD

J. The discussion/conclusion is appropriate.
SA 5 4 3 2 1 SD

K. Despite any flaws, the report is worthy of publication.
SA 5 4 3 2 1 SD

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