Running Head: Glucose and Emotion

The Effects of Glucose Dose and Dual task Performance on Memory for Emotional Material

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Abstract

Whilst previous research has shown that glucose administration can boost memory performance, research investigating the effects of glucose on memory for emotional material has produced mixed findings. Whereas some research has shown that glucose impairs memory for emotional material,l other research has shown that glucose has no effect on emotional items. The aim of the present research was therefore to provide further investigation of the role of glucose on the recognition of words with emotional valence by exploring effects of dose and dual-task performance, both of which affect glucose facilitation effects. The results replicated past research in showing that glucose administration, regardless of dose or dual-task conditions, did not affect the memorial advantage enjoyed by emotional material. This therefore suggests an independent relationship between blood glucose levels and memory for emotional material.

Keywords: Glucose dose, memory, subjective experience, emotion, dual-task performance.

Introduction

Research investigating the effect of glucose ingestion in healthy adults has found significant benefits on cognition including memory performance. This beneficial effect arises across a range of memory tasks such as immediate and delayed free recall, cued recall, long delay recognition, declarative memory, spatial memory as well as working memory [1, 2, 3, 4].

Recent research has now begun to address the possible limitations that glucose administration may have in terms of boosting memory performance, with particular focus on emotional material. The emotional enhancement effect refers to the often reported finding that emotional stimuli are more memorable than their more neutral counterparts (for a review, see [5]). This emotional enhancement effect has been demonstrated across a range of memory measures such as recognition memory [6, 7] and recall [8] and has also been found using a range of stimulus variables including both words [9] and pictures [10]. Moreover, research has shown that the emotional enhancement effect not only consists of a quantitative advantage but also gives rise to qualitative differences in memorial retrieval, in terms of rich episodic 'remembering' [11, 9, 6].

It has long been recognised that emotionally significant, stressful or arousing events can play an important role in the regulation of memory [12]. Acute emotional arousal results in activation of two major endocrine systems, the hypothalamic-anterior pituitary-adrenocortical axis (HPA) and the sympatho-adrenomedullary axis (SAM axis). Activation of the HPA axis is associated with the release of glucocorticoids from the adrenal cortex and activation of the SAM axis leads to a release of adrenaline from the adrenal medulla. A major physiological role of activation of both endocrine systems is considered to be a temporary increase in energy production and more specifically provision of additional metabolic fuel through increase in glucose availability [13]. Consequently, hormonal

activation in response to an arousing/stressful appear to act as endogenous modulators of memory storage processes, with adrenaline being a powerful candidate for this modulating role. Although, considerable progress has been made in characterising biological systems and processes underlying the regulation of memory formation, the aspects of memory affected by stress hormones and the direction of the impact (impairments versus benefits) is still controversial. For example, research exploring the effects of cortisol on memory for emotional and neutral material has produced mixed findings. Whilst some research demonstrated that raised cortisol levels selectively enhanced memory for arousing material [14], other studies have shown that cortisol increased memory performance equally for neutral and emotional (negative) items [15].

The question arises therefore as to whether glucose may have any additional memorial benefits for material such as emotional stimuli that by its very nature already elicits significant increases in memory performance. Preliminary work on the effects of glucose on the recognition of words with emotional valence has demonstrated that the presentation of emotionally arousing material significantly raises plasma glucose levels [16, 17]. However, investigations into the effects of glucose administration on such stimulus material have produced mixed findings. Whereas some studies suggested that in terms of emotional material, glucose ingestion impairs memory performance [18, 17]; others found that glucose administration had no additional effect on the memorial advantage for emotional words [19, 11]. Consequently, it is as yet unclear whether additional glucose administration affects memory for emotional material and if so, whether this effect is beneficial or detrimental. However, there are two possible factors that may have significantly contributed to these discrepant results and it is the aim of the present research to explore these issues in order to gain a fuller understanding of the role of glucose on the recognition of words with emotional valence.

The first factor relates to the dose of glucose that has predominantly been used in memory research. According to recent research [20], the optimal dose of glucose to employ in order to observe

memory improvements in normal participants is 25g for young adults and 50-75g for older adults. However these doses relate to memory performance for neutral stimuli and as previously mentioned, unlike neutral material, emotional material significantly enhances plasma glucose levels [16, 17]. This would suggest therefore that 25g of glucose might not be the optimal dose to employ when using emotional material. This suggestion is supported both by the finding that 50g of glucose impaired memory for emotional material [18] and that 25g of glucose failed to have any effect on emotional material [11]. Thus, it is possible that emotional material shifts the previously assumed glucose dose-response curve to the left, and that any effect of glucose on such material might only be observed at lower doses than have been previously used. It is with this premise in mind that the aim of Experiment 1 was to investigate the role of glucose on the recognition of words with emotional valence using 15g of glucose rather than the 25g normally employed.

The second factor that may have clouded the issue of whether glucose administration has any effect on emotional material relates to task difficulty. It is possible that the depletion of episodic memory capacity and/or glucose-mediated resources in the brain due to performing a concurrent task during memory encoding might be crucial to the demonstration of a glucose facilitation effect. Such a premise is supported by the finding that a glucose facilitation effect was observed under dual-task conditions in memory recall but was not found under full processing conditions [1]. So might dual-task performance elicit a glucose facilitation effect for emotional material? This question was recently investigated in a study looking at the relationship between dual-task performance, blood glucose levels and the recognition of words with emotional valence [21]. Participants in this study were presented with either neutral or emotional words to recall, either in low-effort or high-effort (dual-task) conditions. The results revealed that dual-task performance significantly decreased blood glucose levels for neutral words and decreased memory performance for both neutral and emotional material. In addition, whilst presentation of emotional words lead to significant increases in blood glucose levels, no corresponding increase in memory performance was observed for these items. However previous

research has demonstrated that in order to obtain the emotional enhancement effect, the use of mixed lists (i.e., negative as well as neutral words) as opposed to pure lists (i.e., negative or neutral words) is important [9]. Therefore, the lack of a memorial advantage for emotional words in the previous study [21] may have been due to the use of pure rather than mixed lists. Hence, to date, it is still unclear as to whether dual-task conditions are required in order to observe glucose facilitation effects on the recognition of words with emotional valence. It is therefore the aim of Experiment 2 in the present research to directly address this important issue.

Experiment 1

The aim of Experiment 1 was to investigate whether decreasing the dose of glucose administration from 25g to 15g would have an effect on the emotional enhancement effects previously found both in overall recognition memory and in subjective experiences [11]. Participants were presented with a set of emotionally neutral, positive and negative words to memorise at study. In a subsequent recognition test, participants were required to make old/new judgements for each word and following an old judgment were further required to make remember/know/guess decisions. Based on previous research it was predicted that overall recognition memory would be enhanced for the emotionally negative words in comparison to both the emotionally positive words and the emotionally neutral words and that this pattern of effects would also arise in the subjective experience of 'remembering' [11, 9, 10]. Whilst a dose of 25g of glucose failed to yield effects on recognition of emotional words [11], it was predicted that in the present research, a lower dose consisting of 15g, may well affect the recognition of words with emotional valence.

Methods

Participants

Forty undergraduate students (35 females, 5 males) from the University of Keele participated in the present experiment for which they were paid £5. The range of ages of participants was 18-34 years (mean age = 19.1 years). Participants were not diabetic and had a mean BMI of 22.4 kg/m^2. The Faculty Ethics Committee of the University of Keele approved the experimental procedure prior to the start of the study and all procedures were carried out with written informed consent of the participants.

Treatment

Participants received either 15g of glucose or 3 tablets of aspartame dissolved in 300 ml of water. Three tablets of aspartame were used since, when dissolved in 300 ml of water, the resulting sweetness was rated as equivalent to that of the glucose solution.

Design and Stimulus Materials

The experiment had a double blind, placebo-controlled, between-subjects 2 (condition: aspartame vs. glucose) x 3 (emotion: neutral vs. positive vs. negative) mixed factorial design with repeated measures on the second factor. The stimulus materials were taken from a previous study [11] in which two word lists (Set A and Set B) were created, each containing 60 words of which 20 were emotionally positive (e.g., peace, rainbow), 20 emotionally negative (e.g., corpse, mucus) and finally 20 emotionally neutral (e.g., mirror, cloak). Statistical analyses on these two words lists indicated that they did not differ significantly on frequency, length or imagery. In addition, the words differed significantly in terms of valence [$F(2, 117) = 1305.37$, $p < .001$]. Simple main effects analyses on this effect (supplemented with a Bonferroni correction) revealed that the mean valence rating for negative words (M =2.26) was significantly lower (i.e., more negative) than both the positive (M = 7.70) as well as the neutral words (M = 4.98), $p < .001$. Finally, the mean valence rating for the positive words was significantly greater (i.e., more positive) than that for neutral words, $p < .001$. The lists were counterbalanced such that half the participants in the present study were given Set A as targets and Set B as distracters and the other half were given Set B as targets and Set A as distracters. In addition to the

stimulus materials being counterbalanced across participants, the word lists were also counterbalanced across condition. Participants were randomly allocated to the different experimental conditions as they entered the laboratory.

Procedure

The procedure was identical to that of a previous study [11]. Participants were all tested between 9 and 12 in the morning and were randomly assigned to either the aspartame or the glucose group. A double blind procedure was adopted so that neither the participants nor the experimenter were aware of which condition each person was allocated to. Each participant attended one test session that lasted approximately 50 minutes. Participants were informed that they should not eat or drink anything (except water) for two hours before arriving in the laboratory. All participants were informed that they would undergo cognitive testing related to human memory performance, and that they were required to consume a non-harmful, non-intoxicating drink. Participants were asked to give information about their age, weight, and height.

At the beginning of each session (i.e., before drink ingestion), baseline blood glucose levels were measured. All participants agreed to have their blood glucose levels monitored. They were reassured that they were permitted to withdraw without prejudice during the experiment if they were not willing to have small samples of blood taken. Blood glucose readings were obtained using the ExacTech blood glucose monitoring equipment (supplied by MediSense Britain Ltd, 16/17 The Courtyard, Gorsey Lane, Coleshill, Birmingham B46 1JA), following the manufacturer's recommended procedure. All participants then received either a glucose or an aspartame-containing drink depending on the group they had been allocated to and asked to consume the drink as quickly as possible. There was a 15-minute delay between participants finishing their drink and the start of the study phase. During the study phase, participants were randomly presented with a set of emotionally neutral, positive and negative words and asked to memorise them as their memory for these words

would be tested. Following the study phase, all participants gave a second blood glucose sample and then completed some multiplication problems as a distracter phase for 10 minutes. They were then given the recognition test in which they had to make old/new as well as remember/know/guess judgements. Following the completion of the recognition test, participants gave their third and final blood sample and then were thanked, debriefed, paid and dismissed.

Results

Glycaemic Response

Blood glucose levels were submitted to a 2 (drink: glucose vs. placebo) X 3 (time: i.e., at what point blood glucose was measured; T0 = baseline blood glucose levels, T25 = 25 minutes post ingestion, T45 = 45 minutes post ingestion) mixed factorial ANOVA (see Table 1 for all treatment means). One participant had to be excluded from this analysis due to problems obtaining one blood glucose measurement reading. The analysis on the remaining 39 participants revealed a main effect of drink [$F(1,37) = 37.47$, $p < 0.01$], a main effect of time [$F(2,74) = 29.97$, $p < 0.01$], and a significant drink x time interaction [$F(2,74) = 32.67$, $p < 0.01$]. Simple main effects analyses on this interaction (supplemented with a Bonferroni correction) revealed a significant effect of time on the glucose group [$F(2,38) = 38.84$, $p < .01$] whereby blood glucose levels were significantly greater both at T25 and T45 in comparison to T0. No effects emerged in the aspartame group [$F(2,36) = 1.25$, $p = .29$]. The analyses also revealed that whilst there were no differences between the aspartame and glucose groups at T0, blood glucose levels were significantly greater in the glucose compared to the aspartame group both at T25 [$F(1,38) = 46.12$, $p < .01$] and T45 [$F(1,38) = 37.75$, $p < .01$].

Please insert Table 1 about here

Overall Recognition

Overall correct recognition hits-false alarms were submitted to a 3 (emotion: neutral vs. positive vs. negative) X 2 (condition: aspartame vs. glucose) mixed factorial ANOVA (please see Table 2 for

treatment means). The analysis revealed a main effect of emotion [$F(2,76) = 13.95$, $p < .001$]. Pairwise comparisons were then carried out on this effect using a Bonferroni correction to control the family-wise error rate at the $p < .05$ level. This revealed that recognition of negative words ($M = .60$) was significantly greater than that of both neutral and positive words (respective Ms: .51 vs. .43). No significant differences were found between the neutral and positive words. The effect of condition was marginally significant, [$F(1,38) = 2.96$, $p = .09$], showing that recognition memory was slightly greater in the glucose than the aspartame condition (respective Ms: .55 vs. .48). The emotion X condition interaction was not significant, [$F(2,76) = .24$, $p = .78$, ns]. In order to determine any possible differences in participant sensitivity between the glucose and aspartame conditions, hits and false-alarm scores were collapsed across emotion and converted into A-prime scores and were then submitted to a one-way ANOVA. This analysis revealed that participants' discrimination scores did not differ between the glucose ($M = .85$) and the aspartame conditions ($M = .83$), [$F(1,39) = .67$, $p = .40$, ns].

Please insert Table 2 about here

Subjective Experience

Correct 'remember', 'know' and 'guess' responses were then each submitted to separate 3 (emotion: neutral vs. positive vs. negative) X 2 (condition: aspartame vs. glucose) mixed factorial ANOVAS (see Table 2 for treatment means). The analysis on 'remember' responses revealed a main effect of emotion [$F(2,76) = 10.05$, $p < .01$]. Pairwise comparisons were then carried out on this effect using a Bonferroni correction to control the family-wise error rate at the $p < .05$ level. This revealed that 'remember' responses for negative words ($M = .42$) were significantly greater than that of both neutral and positive words (respective Ms: .30 vs. .28). No significant differences were found between the neutral and positive words. The effect of condition was not significant, [$F(2,76) = .16$, $p = .68$, ns], nor was the emotion X condition interaction, [$F(2,76) = .33$, $p = .71$, ns]. No effects were found in the analyses on either 'know' or 'guess' responses. (See Table 2 for all treatment means).

The results of Experiment 1 have replicated those previously found [11] in showing that overall recognition memory and the subjective experience of remembering is enhanced for emotionally negative in comparison to emotionally positive and neutral words. In addition, unlike the results from our previous study, the present results found a marginal beneficial effect of glucose administration on overall recognition performance. These results will be further explored in the general discussion.

Experiment 2

Previous research suggests that the depletion of episodic memory capacity and/or glucose-mediated resources in the brain due to performing a concurrent task during memory encoding might be crucial to the demonstration of a glucose facilitation effect [22, 1]. As the results of our previous study [11] failed to find an effect of glucose on the recognition of words with emotional valence, and the results of Experiment 1 only showed a marginal effect of glucose in overall recognition memory, the aim of Experiment 2 was to further explore whether an effect of glucose on the recognition of words with emotional valence would arise under dual-task conditions.

Methods

Participants

Forty undergraduate students (13 females, 27 males) from the University of Lancaster participated in the present experiment for which they were paid £5. The range of ages of participants was 18-37 years (mean age = 21 years). Participants were not diabetic and had a mean BMI of 21.1 kg/m^2. Participants received course credits for taking part in the experiment which was approved by the

Department of Psychology Ethics Committee of the University of Lancaster and all procedures were carried out with written informed consent of the participants.

Treatment

Participants received either 25g of glucose or 5 tablets of aspartame dissolved in 300 ml of water. Three tablets of aspartame were used since, when dissolved in 300 ml of water, the resulting sweetness was rated as equivalent to that of the glucose solution.

Design and Stimulus Materials

The design and stimulus materials were identical to Experiment 1.

Procedure

The procedure was identical to that of Experiment 1 with the exception that all participants were required to perform a dual-task during the study phase. While the participants were presented with the word list, they were required to perform two types of complex hand motor sequences (identical to those used in [1] and which were practised with each participant before the first presentation of the word list. Participants were instructed to share their attention equally between the two tasks and were told that they should perform to the best of their ability on each of the two tasks. There were two different motor sequences. Each motor sequence was performed synchronously with both hands. Sequence one comprised ‘fist’-‘chop’-'slap’. Sequence two consisted of ‘back-slap’-‘chop’-‘fist’. Each participant was instructed to complete one sequence of movements between successive words on the list. Participants were also instructed to change between the two sequences every fifth word; i.e., sequence 1 = words 1-5, sequence 2 = words 6-10, sequence 1 = words 11-15 and sequence 2 = words 16-20. Participants were not told the number of words in the list, just instructed to change between sequences every fifth word. Additionally, participants were informed that they would not be told when they should change motor sequence, but should themselves keep

track of the number of words that had been presented. Participants were instructed to remember as many words as they could from the word list whilst carrying out the hand-movement task. As in our previous studies, no rank of importance between the two tasks was communicated to the participant. The ability of participants to perform the hand-movement task was not assessed and incorrect hand-movements were not recorded.

Following the study phase, all participants gave a second blood glucose sample and then completed some multiplication problems as a distracter phase for 10 minutes. They were then given the recognition test in which they had to make old/new as well as remember/know/guess judgements. Following the completion of the recognition test, participants gave their third and final blood sample and then were thanked, debriefed, paid and dismissed.

Results

Glycaemic Response

Blood glucose levels were submitted to a 2 (drink: glucose vs. placebo) X 3 (time: i.e., at what point blood glucose was measured; T0 = baseline blood glucose levels, T25 = 25 minutes post ingestion, T45 = 45 minutes post ingestion) mixed factorial ANOVA (see Table 3 for all treatment means). One participant had to be excluded from the analysis due to problems obtaining one of their blood glucose measurements. The analysis on the remaining 39 participants revealed a main effect of drink [$F(1,37) = 62.05$, $p < 0.01$], a main effect of time [$F(2,74) = 64.71$, $p < 0.01$], and a significant drink x time interaction [$F(2,74) = 28.07$, $p < 0.01$]. Simple main effects analyses on this interaction (supplemented with a Bonferroni correction) revealed a significant effect of time on the glucose group [$F(2,38) = 70.63$, $p < .01$] whereby blood glucose levels were significantly greater both at T25 and T45 in comparison to T0, and higher at T25 than T45. The results also revealed a significant effect of time on the aspartame group [$F(2,36) = 4.95$, $p < .02$] whereby blood glucose levels were significantly greater at T25 than at T0. The analyses also revealed that whilst there were no differences between the aspartame and glucose

groups at T0, blood glucose levels were significantly greater in the glucose compared to the aspartame group both at T25 [$F(1,38) = 68.77$, $p < .01$] and T45 [$F(1,39) = 40.86$, $p < .01$].

Please insert Table 3 about here

Overall Recognition

Overall correct recognition hits-false alarms were submitted to a 3 (emotion: neutral vs. positive vs. negative) X 2 (condition: aspartame vs. glucose) mixed factorial ANOVA (please see Table 4 for treatment means). The analysis revealed a main effect of emotion [$F(2,76) = 7.71$, $p < .01$]. Pairwise comparisons were then carried out on this effect using a Bonferroni correction to control the family-wise error rate at the $p < .05$ level. This revealed that recognition of negative words ($M = .33$) was significantly greater than positive words but only marginally greater ($p = .07$) than neutral words (respective Ms: .18 vs. .26). In addition, recognition of neutral words was greater than that of positive words. The effect of condition just fell short of being significant, [$F(1,38) = 3.89$, $p = .05$], showing that recognition memory was marginally greater in the aspartame than the glucose condition (respective Ms: .30 vs. .21). The emotion X condition interaction was not significant, [$F(2,76) = 1.12$, $p = .33$, ns]. Participants' hits and false-alarm scores were then collapsed across emotion, converted into A-prime scores and submitted to a one-way ANOVA. This analysis revealed that participants' discrimination was significantly higher in the aspartame ($M = .75$) in comparison to the glucose condition ($M = .68$), [$F(1,39) = 7.06$, $p < .01$]. In order to determine the contributing factor (i.e., hits or false-alarms) that gave rise to this effect, participants' hits and false-alarms were each submitted to a one-way ANOVA. The analyses revealed that whereas no differences in hit-rate were found between the glucose ($M = .48$) and the aspartame condition ($M = .50$), [$F(1, 39) = .04$, $p = .83$, ns], the false-alarm rate in the glucose condition ($M = .27$) was significantly greater than that in the aspartame condition ($M = .18$), [$F(1,39) = 4.29$, $p < .05$],

Please insert Table 4 about here

Subjective Experience

Correct 'remember', 'know' and 'guess' responses were then each submitted to separate 3 (emotion: neutral vs. positive vs. negative) X 2 (condition: aspartame vs. glucose) mixed factorial ANOVAS (see Table 4 for treatment means). The analysis on 'remember' responses revealed a main effect of emotion [$F(2,76) = 14.05$, $p < .01$]. Pairwise comparisons were then carried out on this effect using a Bonferroni correction to control the family-wise error rate at the $p < .05$ level. This revealed that 'remember' responses for negative words (M =.30) were significantly greater than that of both neutral and positive words (respective Ms: .18 vs. .16). No significant differences were found between the neutral and positive words. The effect of condition was not significant, [$F(2,76) = .05$, $p = .82$, ns], nor was the emotion X condition interaction, [$F(2,76) = .64$, $p = .52$, ns]. A marginal effect of condition was found in 'know' responses [$F(2,76) = 3.4$, $p = .07$] indicating that know responses were slightly higher in the aspartame than the glucose condition (respective Ms: .07 vs. .01). No effects were found on 'guess' responses. (See Table 4 for all treatment means).

The results of Experiment 2 have replicated those of Experiment 1 showing that even under dual-task conditions, overall recognition memory and the subjective experience of remembering is enhanced for emotionally negative in comparison to emotionally positive and neutral words. However, whilst no effect of glucose was found, a near significant effect was demonstrated showing that overall recognition memory was greater in the aspartame in comparison to the glucose group. Furthermore, this effect appears to be largely due to fewer false-alarms rather than correct recognition. These results will be further explored in the general discussion.

General Discussion

Previous research exploring the role of glucose on the recognition of words with emotional valence has produced mixed findings, with some research showing that glucose impaired memory

performance for emotional compared to neutral items [16] whereas other studies found that glucose failed to have any effect on emotional material [11]. The aim of the present research was to provide further exploration on what role glucose might play on the recognition of words with emotional valence by exploring two factors; dose of glucose and dual-task performance, both of which have significantly influenced effects of glucose in past research [20, 1] and therefore which might contribute to the relationship between glucose administration and memory performance for emotional words.

Experiment 1 of the present research investigated the effects of reducing the dose of glucose from 25g to 15g. Previous research has shown that 50g of glucose impairs memory for emotional material [18] whereas 25g of glucose has no effect on these stimulus items [11] and therefore these results suggest the possibility that any effects of glucose on emotional material may only be observed at lower doses. The results of Experiment 1 replicated those found previously [11]. Specifically, glucose administration lead to significant increases in blood glucose levels at T25 and T45 in comparison to both T0 and the aspartame control. In addition, regardless of condition, emotionally negative words were recognised to a significantly greater extent than both neutral and positive words, and this effect was also reflected in the subjective experience of remembering. These results are also consistent with research showing greater recognition memory and remembering for emotionally negative compared to neutral pictures and reveal that emotional material benefits from both a quantitative and qualitative memorial advantage regardless of stimulus domain.

The finding that the emotional memory enhancement effect in the present research was found both under conditions where significant changes in blood glucose were observed (i.e., the glucose condition) and where no changes in blood glucose levels were found (i.e., the aspartame condition in Experiment 1) also supports the findings that changes in blood glucose levels are not necessary for emotional arousal to enhance recognition memory [23]. This tentatively suggests an independent relationship between blood glucose levels and the recognition of words with emotional valence, a

suggestion which is further supported by the finding in the present research of a marginal effect showing that overall recognition memory was greater under conditions of glucose administration than the control group. At first glance, this finding would tentatively suggest that 15g rather than 25g of glucose is a more appropriate dose to use to detect any effects with emotional material, thereby also implying such stimulus items shift the previously assumed dose-response curve between glucose and memory performance [20]. However, this marginal beneficial effect of glucose related to overall memory performance and hence did not pertain to the emotional words specifically. Although this memorial benefit was marginal and hence future research is required, these results suggest that whilst 15g of glucose may be a more appropriate dose to use with emotional material, any beneficial effects of glucose will not actually be related to such material, but will instead contribute to a general boost in memory performance across all stimulus items.

Experiment 2 of the present research investigated the effects of dual-task performance and glucose on the recognition of words with emotional valence. Given the observation that dual-task performance has sometimes been necessary in order to elicit any memorial benefit of glucose [1], it has been argued that the depletion of episodic memory capacity and/or glucose-mediated resources in the brain under such task conditions is crucial to the demonstration of a glucose facilitation effect. The aim of Experiment 2 was to test this prediction. Analysis of the blood glucose data revealed that blood glucose levels in the glucose group were significantly greater at both T25 and T45 in comparison to T0 and to the control group. Interestingly, within the control, group blood glucose levels were significantly greater at T25 compared to baseline. These findings are in line with the suggestion that i) emotional material can significantly increase blood glucose levels [16, 11] and ii) that the hyperglycaemic effect of emotional material prevails over the hypoglycaemic effects of performing a secondary motor task [21]. However, as the current experiments were not specifically designed to test these notions, this issue will have to remain one for speculation. Further research is clearly needed to clarify whether relatively low level increases in arousal lead to a significant rise in blood glucose levels and whether

dual task performance and/or performance of cognitively demanding tasks does indeed lead to a decrease in peripheral and/or central blood glucose levels. Indeed there is evidence suggesting that performance of a secondary task does not significantly alter blood glucose levels [1].

Regarding memory performance, the results of Experiment 2 demonstrated that regardless of condition, emotionally negative words were recognised to a significantly greater extent than both neutral and positive words (though the effect with neutral words was only marginal), and this effect was also reflected in the subjective experience of remembering. These findings not only replicate those previously found [11] and those from Experiment 1 of the present research under full-attention conditions, but importantly also demonstrate the persistence and robustness of the emotional enhancement effect, both in quantitative and qualitative terms within recognition memory. Interestingly, the results revealed a marginal main effect of condition, whereby overall memory performance was marginally greater in the aspartame compared to the glucose group. Further analyses relating to this effect demonstrated that discrimination scores were significantly greater in the control group and more importantly, that whereas correct hits were similar across both groups, there was a significantly greater elicitation of false alarms in the glucose group. These results suggest that glucose administration impairs the recognition of words with emotional valence under dual-task conditions by increasing the propensity that participants will make incorrect memory judgements. The cognitive difficulty of the memory task has proven to be sufficient to elicit glucose facilitation for neutral material [1]. Therefore, the observed lack of a memory boost following glucose administration is unlikely to be due to lack of task difficulty. It appears that glucose administration and the presentation of emotional material (which in itself raises blood glucose) leads to glucose levels which reach a cut-off point at which glucose no longer benefits memory performance even when the memory task is sufficiently difficult.

The results of the present research also revealed that neutral words were recognised to a greater extent than positive words, which has not previously been demonstrated [11, 9, 10]. At first glance, this finding would suggest that dual-task performance appears to impair memory for positive words however it is unclear as to why this might be the case. What is important to note however, is that the memorial benefits associated with positive material appear to be inconsistent. Previous research found that emotionally positive words were recognised more than neutral words [9], a finding replicated using emotional pictures [10]. However recently research [11] failed to replicate this advantage for positive material using the same stimulus items as a previous study [9]. It seems apparent therefore, that the memorial advantage associated with positive material is inconsistent, unlike that for emotionally negative material [5] which further suggests that it is negatively-valenced material which is the predominant factor in driving the emotional enhancement effect in recognition memory.

Conclusion

The aim of the present research was to provide further exploration on what role glucose might play in the recognition of words with emotional valence by exploring two factors; dose of glucose and dual-task performance. Despite decreasing the dose from 25g to 15g, the only effect glucose administration had was to marginally increase overall memory performance for all stimulus items, irrespective of emotional valence. In addition, dual task performance did not lead to glucose facilitation for words of emotional valence. Not only was no memorial advantage found in comparison to the control condition, but additionally incorrect memory was significantly greater within the glucose group. Taken together with previous work, the results of the present research suggest that the emotional enhancement effect is both persistent and robust and that even when using low dosage and in the presence of dual task performance, memory for emotionally arousing material is not enhanced by systemic glucose administration. That is to say, the hyperglycaemic effects of presentation of emotional material make additional glucose administration redundant and even detrimental for emotional items to elicit both quantitative and qualitative advantages within recognition memory.

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Table 1.

Blood glucose levels (mmol/L) as a function of condition and time (Exp.1).

	Time		
	T0	T25	T45
Condition			
Glucose	5.03 (.48)	7.50 (1.19) **	6.91 (1.16) **
Aspartame	5.31 (.74)	5.32 (.74) **	5.13 (.48) **

Note. Standard deviations in parentheses. Following glucose administration, blood glucose levels were significantly greater both at T25 and T45 in comparison to T0 and compared to the aspartame group both at T25 and T45. Levels of statistical significance for comparison of blood glucose levels following glucose administration compared to placebo and baseline are depicted with asterisk: **, $p<0.01$.

Table 2.

Recognition performance (Hits-False Alarms) as a function of condition, word valence and subjective experience (Exp.1).

	Word Valence		
	Neutral	Negative	Positive
Condition			
Aspartame			
Overall	.46 (.14)	.57 (.13)	.39 (.15)
Remember	.30 (.23)	.39 (.19)	.27 (.15)
Know	.17 (.15)	.20 (.15)	.14 (.15)
Guess	-.01 (.09)	-.01 (.04)	-.01 (.07)
Glucose			
Overall	.56 (.23)	.62 (.17)	.46 (.18)
Remember	.31 (.29)	.44 (.24)	.28 (.22)
Know	.23 (.20)	.19 (.15)	.17 (.24)
Guess	.02 (.06)	-.01 (.04)	.01 (.06)

Note. Standard deviations in parentheses.

Table 3.

Blood glucose levels (mmol/L) as a function of condition and time (Exp.2).

	Time		
	T0	T25	T45
Condition			
Glucose	4.90 (.50)	8.12 (1.15) **	7.31 (1.29) **
Aspartame	4.59 (.70)	5.27 (.98) *	5.05 (.90)

Note. Standard deviations in parentheses. Following glucose administration, blood glucose levels were significantly greater both at T25 and T45 in comparison to baseline and following placebo. A significant rise in blood glucose levels also was observed in the placebo group at T25 compared to baseline. Levels of statistical significance are depicted with asterisk: *, $p<0.05$; **, $p<0.01$.

Table 4.

Recognition performance (Hits-False Alarms) as a function of condition, word valence and subjective experience (Exp.2).

	Word Valence		
	Neutral	Negative	Positive
Condition			
Aspartame			
Overall	.29 (.18)	.36 (.17)	.26 (.25)
Remember	.17 (.15)	.30 (.21)	.18 (.12)
Know	.09 (.10)	.04 (.14)	.08 (.15)
Guess	.03 (.07)	.01 (.10)	-.01 (.09)
Glucose			
Overall	.23 (.17)	.30 (.23)	.10 (.19)
Remember	.19 (.19)	.29 (.22)	.14 (.16)
Know	.05 (.14)	.01 (.17)	-.01 (.12)
Guess	-.01 (.05)	-.01 (.03)	-.02 (.06)

Note. Standard deviations in parentheses.