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Effects of glucose and sucrose on mood: a systematic literature review of interventional studies

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Context: Glucose is the main energy source for the brain and as such, manipulation of glucose supply may affect brain function. It has been suggested that a change in blood glucose may influence mood. ***Objective:*** To investigate the potential effects of glucose and sucrose, compared to placebo, on mood. ***Data Sources:*** The electronic databases Pubmed and Scopus were searched until May 2017. Reference lists of selected articles were checked manually. ***Study Selection:*** Randomized controlled trials or crossover trials comparing the effects of glucose or sucrose on mood. ***Data Extraction:*** Potentially eligible articles were selected independently by 2 reviewers. ***Results:*** In total, nineteen studies were found. Thirteen studies investigated the effects of glucose consumption compared to placebo on mood. Seven of these thirteen studies found no effect of glucose on mood. The other six studies found small and partial effects that may also be due to other factors like palatability and expectation. Seven of the nineteen studies investigated the effects of sucrose ingestion versus placebo on mood. None of these studies found a positive effect on mood and one study observed an adverse effect. ***Conclusions:*** The results from this review show limited effects of glucose ingestion on mood and no effect of sucrose on mood.

Keywords*:* sugar, glucose, sucrose, mood

INTRODUCTION

Glucose is the main source of energy of the human brain. The brain constitutes only about 2% of the human body weight, but consumes nearly 20% of oxygen and 25% of the glucose consumed by the human body due to its high metabolic activity[1]. Neurons have the highest energy demand in the adult brain[2]. Since the activity of these cells is constant and they have a limited ability to store glucose themselves continuous supply of glucose from blood is needed to keep glucose levels stable. Glucose levels can be increased by direct intake of glucose, a monosaccharide sugar unit, or sucrose, a disaccharide sugar unit made up of the two monosaccharide sugar units glucose and fructose and more commonly known as 'table sugar'. Manipulation of the tight regulation of brain glucose metabolism may play a role in brain functioning, such as cognition and mood. Thus, a beneficial role of glucose loads on cognitive functioning, episodic memory in particular, has been suggested[3, 4]. The effect of glucose and sucrose containing drinks on mood was reviewed in 2002 and the results were inconsistent[5].

The objective of this literature review is to provide an overview of interventional studies that investigated the effect of glucose or sucrose intake compared to placebo on mood in healthy adults.

METHODS

For this systematic review the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[6] were followed. A predefined protocol was not available.

Data sources and literature search

The Pubmed database was searched for suitable articles up to May 2017. The following search terms were used: ("glucose"[All Fields] OR "sucrose"[All Fields]) AND ("mood"[All Fields] OR "mood state"[All Fields]) NOT ("diabetic"[All Fields] OR "diabetes"[All Fields]) AND "humans"[MeSH Terms]. Titles, abstracts and keywords were carefully examined to select articles. A parallel search in Scopus was performed to check for additional papers. Reference lists of identified manuscripts and reviews were checked manually.

Eligibility criteria

Table 1 shows the PICOS criteria used to define the research question. Studies that fulfilled to the following criteria were eligible: participants were healthy adults; the intervention comprised glucose or sucrose and was compared with a matching placebo; study design was a randomized controlled or crossover trial with mood as an outcome measure; and the article was published in English. Studies performed in individuals with a psychological disorder,diabetes or other medical conditions and studies in which glucose or sucrose was co-administered with other substances were excluded.

RESULTS

Study selection

Figure 1 shows the study selection process. The initial search yielded 474 potentially appropriate studies. After screening of titles and abstracts 437 articles were excluded. Full texts of the remaining 37 papers were reviewed. Of these, in total 19 intervention studies met the inclusion criteria for this review of which thirteen studies on the effect of glucose ingestion and seven studies on the effect of sucrose on mood. One of the studies assessed the effects of both glucose and sucrose on mood within one study[4]. Ten studies used a within-subjects cross-over design and ten a between-subjects parallel design. A detailed overview of studies that addressed the effect of a glucose intervention on mood is provided in **Table 2** and an overview of studies on sucrose interventions on mood in **Table 3.**

GLUCOSE INTERVENTIONS

Thirteen studies examined the effects of glucose drinks on mood. Eight of these studies used a within-subjects cross-over design[4, 7-13] and five studies used a parallel between-subjects design[14-18].

The most recent study was performed in seventeen male participants aged 19-40 years (mean age 28.5 years)[12]. Using a cross-over design the effects of glucose (25g), caffeine or a placebo on mood after performance of an extensive battery of cognitive tests were investigated with the Positive and Negative Affect Schedule (PANAS)[19]. Participants tended to feel more sad and more depressed 2 hours after glucose when compared to placebo.

Scholey et al. performed a parallel intervention study in 150 males and females within the age range of 18-55 years (mean age 34.8 years). Effects of different doses of glucose (25g, 60g or 60g + 40mg caffeine) versus placebo on

mood were assessed with Bond-Lader[20] and Visual Analogue Mood Scales (VAMS) before and after a 30-minute multi-tasking framework. No significant treatment effects on mood for any of the doses were found[16].

The smallest study was a cross-over study performed in ten healthy men (mean age 22 years) in a dehydration condition[10]. Participants were permitted to drink the glucose or non-glucose drink ad-libitum for 30 minutes. Mood was measured as a secondary outcome using the Profile of Mood States – Short Form (POMS-SF)[21]. No effect of the glucose drink on any of the mood measures as compared to the non-glucose placebo drink was found.

Another study included 43 elderly participants (mean age 77.7 years)[4]. Compared to placebo, a dose of 50g glucose had no effect on POMS-SF scores directly after the drink or 90 minutes later after performance of an extensive cognitive test battery. However, compared to sucrose, a better vigor-score at t=0 (p=0.02) and t=90 (p=0.05) and a better depression-score at t=0 (p=0.02) were observed after the glucose drink.

In a study by Jones et al. the effects of 40g glucose were compared with a placebo drink (2g aspartame) and also with those of 16g fat or 40g protein in 18 healthy young adults with a mean age of 19 years. Only a main effect of time on the BOND Lader VAMS factor alertness was found, no effect of glucose or the other macronutrients[13].

Owen et al. tested six different test conditions in a cross-over study in 30 young adults (mean age 20 years)[9]. Drinks with either 0, 25 or 60g glucose were tested after both a 2-hour and 12-hour fasting period. No significant main effects of drinks, fasting interval or time on subjective mood measures as assessed with Bonder-Lader VAMS were found. However, 20 minutes after the drink and also 47

minutes after the drink and cognitive testing the reduction in calmness was greater following 25 g and 60 g glucose compared to placebo.

Sunram-Lea et al. also investigated the effect of different doses of glucose (0g, 15g, 25g, 50g, 60g) on mood[11]. In 30 healthy young participants aged 18-25 years (mean age 20 years) the different glucose doses led to significantly different glycemic responses ($p<0.0001$), but for none of the doses versus placebo a significant effect was found on the subjective Bond-Lader VAMS measures.

In 2009 another study by Scholey et al. was performed in 120 healthy volunteers (77 females) with a mean age of 21.6 years. In this randomized, double-blind, placebo-controlled parallel groups trial the effect of a drink with 25g glucose was compared with a placebo drink (30mg saccharine). No differential effect of the drinks was found on VAS scales measuring alertness and overall mood[18].

Markus included 37 young adults between 18 and 25 years of age and observed that an orange drink high in glucose (2x 200 ml, 184 kJ/100ml) as compared to a control (2x 200 ml, 0.3 kJ/100ml) positively influenced mood under cold pressor stress, as was shown by increased feelings on the POMS subscale vigor and decreased feelings of fatigue[8].

In a parallel study in 45 young adults with a mean age of 22.6 years Scholey et al. did not find differential effects of a glucose drink (25g) compared to placebo on POMS scores[17].

Another study examined the effect of expectancy in relation to glucose (50g) in 26 adults between 18 and 40 years of age[7]. Mood was assessed as a secondary outcome using 14 100mm VAMS. A three-way interaction for the rating ‘dejected’ was found ($p=0.016$). The scores for dejection differed when subjects expected and received glucose versus subjects who expected glucose but received placebo

154 ($p<0.05$). Also an overall decrease in energetic rating was found at each test session
155 ($p=0.26$).

156 In three separate studies performed in healthy young adults with a mean age
157 around 22 years and comprising respectively 96 males and females, 50 males, and
158 70 females, a fall in blood glucose after completing a frustrating, impossible cognitive
159 task was associated with feeling less energetic (Activation-Deactivation Adjective
160 Check List (AD-ACL)[22]). The active drink contained 50g of glucose and in the second
161 and third experiment a second drink containing 25g of glucose was provided after 20
162 minutes[15].

163 Consumption of a glucose drink (50g or 50g + additionally 2 times 25g after 45
164 and 75 min in the second and third experiment) resulted in fewer negative responses
165 in another study using this frustrating task in a large study population of 354 young
166 adults with a mean age of 21.7 years and also in feeling less tense (AD-ACL) in two
167 other experiments without the frustrating task performed in the same study
168 population[14].

169

170 **SUCROSE INTERVENTIONS**

171 Seven studies used sucrose drinks as intervention. Two studies used a cross-over
172 design[4, 23] and five studies were parallel studies[24-28].

173 In a cross-over study performed in 43 elderly participants (mean age 77.7
174 years) the sucrose drink (100g), compared with placebo, increased feelings on the
175 POMS-SF components tension and depression 90 minutes after consumption and
176 performance of a cognitive test battery[4]. This study was also mentioned under the
177 glucose studies because also a glucose drink was used, which, compared to

sucrose, showed a better vigor score at t=0 (p=0.02) and t=90 (p=0.05) and a better depression score at t=0 (p=0.02).

In a 4-week parallel study performed in 53 overweight (BMI range: 25-30 kg/m^2) women with a mean age of 34 years the differential effect of daily consumption of two soft drinks, sucrose sweetened a Scottish carbonated soft drink (Irn-Bru, 4x250 ml/day, 180kJ/100ml) and aspartame sweetened Irn-Bru (4x250 ml/day, 17kJ/100ml) was investigated[27]. The two different drinks had no effect on mood ratings on ten visual analogue scales.

Another 4-week parallel study was conducted by the same research group, this time in 133 normal weight women with a mean age of 32 years[28]. The effect of sucrose-sweetened Irn-Bru (4x250 ml/day, 180kJ/100ml) as compared to the aspartame sweetened diet Irn-Bru (4x250 ml/day, 17kJ/100ml) on long-term dietary compensation for added sugar was investigated. Mood scores, which were included as a secondary outcome, were assessed with ten visual analogue scales and varied significantly as a function of time of day, but no effect on mood was found as result of the different drinks.

Reid and Hammersley performed a parallel study in 45 obese and 45 non-obese women aged around 34 years[26]. Mood, measured with the bipolar form of the Profile of Mood State (POMS-BI), was not affected by either the sucrose (40g) or placebo (saccharin and water) drinks. Women with a high drive for thinness tended to rate themselves as more clearheaded 30 minutes after any preload. The trend for feeling less clearheaded immediately after the sucrose drink was not significant.

Another parallel study by Reid and Hammersley was performed in 60 normal weight young adults (age range 18-55 years)[25]. No effect of sucrose (40g) vs. the saccharin or water placebo drinks on any of the six POMS subscales was found

immediately or after 30 or 60 minutes of intake. A small effect of sucrose on energy levels 30 minutes later was found, but this comprised only an effect in two out of four women.

A cross-over study performed in 1990 in 120 young women (mean age 20 years) observed greater sleepiness scores on the Stanford Sleepiness Scale (SSS)[29] after a sucrose (50g, 12oz) sweetened drink compared to both an aspartame-sweetened and unsweetened control drink[23]. No differential effects on mood states, as measured with both VAMS and POMS, were found.

Brody and Wolitzky performed a parallel study in 53 undergraduate students (mean age 18.7 years) who received either a sucrose solution (100g), a saccharin solution or water[24]. Mood was assessed using the National Institute of Mental Health (NIMH) mood scale[30] before and 20 minutes and four hours after consumption. Sucrose did not affect mood more than saccharin or water did.

DISCUSSION

In this literature review the results of thirteen intervention studies investigating the effect of glucose and seven intervention studies on the effect of sucrose on mood were evaluated. Seven of the thirteen studies that applied a glucose intervention found no effect of glucose ingestion on mood. The other six studies found small beneficial effects on one or two of the assessed mood measures (mostly feeling less tense and/or more energetic) or when the study conditions induced a stressful condition[8]. None of the studies with a sucrose intervention found a beneficial effect and one study even observed an adverse effect[4].

Of the glucose studies that found a limited effect this was probably due to other factors than solely the ingestion of glucose or sucrose. Green et al. found an effect on the mood state 'dejected', but this was not induced by the glucose drink, but by the expectancy for the glucose drink[7]. Another factor affecting the results of glucose on mood may be the presence of a (cognitive) demanding situation, such as performance of cognitively demanding tasks or stressful conditions, as this will increase the brain's need for glucose[3]. It has been hypothesized that under such conditions there could be a stronger association between mood and blood glucose levels[15]. The brain has a high metabolic rate and when performing cognitively demanding tasks the brain's need for glucose will increase. As a consequence mood may then be more influenced by the supply of glucose[31, 32]. However, the majority of the glucose studies in this literature review included a kind of, mainly cognitively, demanding condition, butthis theory was only (partly) confirmed by three of the studies[8, 14, 15].

Van der Zwaluw et al. found an increase in negative emotion after sucrose ingestion, but this effect was probably due to the fact that the sucrose drink was less

palatable than the placebo drink[4]. Mood may be affected by sweet and palatable taste: studies applying other interventions than glucose or sucrose have found associations between improvements in mood and higher palatability of for example chocolate[33] or an iced desert[34]. In some studies[25, 26] this orosensory factor was largely eliminated by asking the participants to suck on a benzocaine anesthetic lozenge which caused mild anesthesia of the mouth.

Study findings may depend on the dose of glucose or sucrose that is used, which was mostly 50 grams of glucose per drink and sometimes 25 grams. For sucrose studies either 40, 50 or 100 grams of sucrose were ingested, but none of the studies observed mood effects. This also applied to the studies that did not only provide one sucrose drink to investigate acute effects, but assessed longer-term effects by providing four sucrose drinks daily for a period of four weeks[27, 28]. Three studies used multiple doses of glucose ranging between 15 and 60 grams of glucose per drink[9, 11, 16]. Only in the study of Owen et al. some differential effects per dose were found on calmness, but this was not very consistent. Therefore, the optimally effective dose of glucose is not clear yet. Moreover, the dose may also depend on the extent to which an increase in glucose levels is needed, such as for example determined by the intensity of a demanding task or the preceding fasting time. Owen et al. assessed glucose effects after a 2 hour and 12 hour fasting period, but did not find differences[9]. However, based on a recent fMRI study, controlling for fasting state and glucose levels is recommended because these conditions affect brain activation on mood regulation[35].

As also described by Benton[5] another major variable affecting glucose and sucrose effects appears to be the timing of the mood assessment after consumption of sugar intake. After ingestion of a sugar containing drink there appears to be a

short-term increase of energy about 30-60 minutes after intake. This increase is followed by a longer-term fall in subjective energy about 120 minutes after intake. So increased[14] or decreased subjective energy will be measured, depending on time of assessment of mood. An additional factor affecting timing of mood assessment is whether there were demanding situations, requiring increased glucose resulting in faster lowering of glucose levels, in between. With respect to timing two studies of Reid et al. should be mentioned separately here, because they did not assess the acute effects of sucrose, but the effects over a 4-week period of time which was considered a long-term study[27, 28].

The limited number of subjects included in the majority of the studies could also be an explanation for finding little support for glucose and/or sucrose effects on mood. The study performed in 1993[14] found a small effect of glucose on the relief of tension and used by far the largest study population (n=354). The authors already mentioned that the effect was probably harder to find in a smaller population. The second largest study using glucose as intervention included 150 participants and the largest study with a sucrose intervention comprised 133 participants. All the other study sizes were much smaller, so could indeed have been too small to pick up results.

Mood is a subjective measure, so it is important to use validated questionnaires to assess mood. The original 65-item Profile of Mood States (POMS)[36] and its shorter 37-item version[21] are both validated and commonly used questionnaires[37]. The large majority of the studies included in this review used the POMS, POMS-SF or POMS-BI to assess mood. Six other studies used Bond-Lader[20] or other visual analogue mood scales (VAMS) which have shown good reproducibility and validity. The remaining studies used either the Positive and Negative Affect

Schedule (PANAS)[19], the Activation-Deactivation Adjective Check List (AD-ACL)[22], or the National Institute of Mental Health (NIMH) mood scale[30]. Generally, the POMS or its sub-forms are recommended and using similar measures across studies would improve comparison of the results[38].

Only one of the glucose and sucrose studies was performed in elderly people (mean age 77 years)[4], all the other studies were done in young adults with a mean age between about 20 and 35 years of age. Therefore, the results could only be applied to young adult populations. The study performed in older adults observed no positive effects of glucose versus placebo, but some beneficial effects of glucose over sucrose. Sucrose versus placebo, however, showed increased negative emotions. Though, as also mentioned earlier, this negative effect could have been due to lower palatability of the sucrose drink. More studies in older populations will be needed to further investigate these findings.

In 2002, already fifteen years ago, an earlier review on blood glucose and mood was published[5]. The present review includes multiple additional and particularly more recent studies that investigated glucose and sucrose effects on mood. Our review is more complete and detailed and is slightly more focused regarding inclusion of studies: only studies that have contrasted glucose or sucrose containing drinks compared to placebo were included. Thus studies comparing carbohydrate-rich foods or meals versus those rich in protein were beyond the scope of the current review. Furthermore, studies performed in diabetic patients or individuals with psychological disorders were excluded, because those disorders influence blood glucose levels or mood and therefore the results may limit translation to healthy individuals. However, overall the conclusions are still largely in line with those from Benton's review[5].

CONCLUSION

The results from the present review suggest that there is no clear acute effect of glucose and sucrose ingestion on mood. The largest benefits were seen when conditions were demanding due to stressful conditions and within the first 15-60 minutes after ingestion. It is, however, not clear whether effects are solely due to increased blood glucose. More research, including large study populations, validated scales and proper timing of mood assessment, and taking into account fasting state and glucose levels could be done to further investigate this effect. Furthermore, since only one study is performed in elderly individuals research could also be expanded to this group. As a final note we would like to mention that making recommendations for regular intake of pure glucose, sucrose, or products that contain large amounts of added sugars is difficult seen the possible negative long-term health effects regarding for example obesity and, if too frequently used, dental caries.

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Figure 1 **Flow diagram of the literature search process.**

Table 1 **PICOS criteria for inclusion of studies**

Parameter	Description
Population	Healthy adults, without a psychological disorder or diabetes
Intervention	Glucose or sucrose
Comparison	Matching placebo
Outcome	Mood
Setting	Randomized controlled or crossover trial

Table 2 **Overview of studies investigating the effect of glucose compared to placebo on mood**

Reference	Population and study design	Mood measure	Results
Ullrich et al. (2015)[12]	N=17 (males), age range 19-40 yr, mean age 28.5 ± 4.4 yr. Double-blind, balanced, placebo-controlled cross-over study, 3 separate test days. Caffeine (200g) drink + artificially sweetened placebo (sucralose), glucose drink (25g) + a decaffeinated placebo coffee or placebo condition with decaffeinated placebo coffee + artificially sweetened placebo	Adapted PANAS scales, at t=0 and t≈120min after cognitive demanding condition	No significant changes in mood after glucose vs. placebo. However, participants tended to feel more sad (Z=-1.46, p=0.15, r=-0.35) and more depressed (Z=-1.39, p=0.16, r=-0.34) after glucose vs. placebo 2h after cognitive tests.
Scholey et al. (2014)[16]	N=150 (males and females), age range 18-55yr, mean age 34.8 yr. Double-blind, placebo-controlled, randomized, parallel groups study. Glucose drinks (25g, 60g or 60g + 40mg caffeine) vs. placebo (sugar-free fizzy orange drink)	Bond-Lader and stress and fatigue VAMS at t=0 & t=30min after multi-tasking framework	No significant treatment effects on mood of glucose vs. placebo.
Seo et al. (2014)[10]	N=10 (males), mean age: 22 ± 2 yr. Cross-over study; two separate test days. Glucose containing beverage (ad libitum) vs. non-glucose beverage	POMS-SF, from which TMD is calculated, before, directly after & 30min after dehydration condition	No significant effect for condition (p=0.554), time (p=0.053) and time by condition interaction (p=0.053) on POMS TMD. POMS TMD was not different between the two conditions.
van der Zwaluw et al. (2014)[4]	N=43 (older men and women with self-reported memory complaints), age ≥70 yr, mean age: 77.7 ± 5.6 yr. Cross-over study: three 1-day test trials with 1-week washout period.	POMS-SF, t=0 min (before drink) & t=90min, in cognitive demanding situation	Glucose vs. placebo: no difference in mood. Glucose vs. sucrose: Better vigor-score at t=0 min. (p=0.02) and at t=90 (p=0.05). Better depression-score at t=0 (p=0.02).

	Glucose drink (50g), sucrose drink (100g), placebo (artificial sweetener).		
Jones et al., (2012)[13]	N=18 (healthy young adults), mean age 19 yr. Blind, placebo-controlled, balanced, randomised cross-over study. Drinks with either 40g glucose,16g fat or 40g protein vs. placebo drink (aspartame)	16 Bond and Lader VAMS with factors 'alertness', 'calmness, and 'contentment' immediately after cognitive tests	Only a main effect of time: higher alertness ($F(1,16)=7.23$, $p<0.01$) 10 min post-drink, no differential effect of the glucose drink compared to placebo
Owen et al. (2012)[9]	N=30, age range 18-25 yr, mean age 20 yr. Double-blind, placebo-controlled, balanced, 6-period cross-over study. Drinks with either 0g, 25g or 60 g glucose after either a 2hr or 12 hr fast	Bond-Lader VAMS with factors 'alertness', 'contentedness', and 'calmness' at t=0, t=20 & t=47min	No significant main effects of drink on mood measures were observed. Neither for fasting interval or time. Reduction in calmness was significantly greater following placebo than 25g glucose both at t=20 ($t(27)=3.14$, $p<0.01$) and t=47min ($t(27)=2.83$, $p<0.05$) and after 60g glucose compared to placebo at t=20 ($t(27)=2.04$, $p<0.05$) and t=47min ($t(27)=2.53$, $p<0.05$).
Sunram-Lea et al. (2011)[11]	N=30 (young and healthy), age range 18-25 yr, mean age: 20 yr. Cross-over study: five test sessions with a 24h washout period. Drinks containing different doses of glucose (0g, 15g, 25g, 50g, 60g)	Bond-Lader VAMS before and directly after the drinks & extensive memory tests	No effect of glucose vs. placebo on any of the subjective mood measures.
Scholey et al., (2009)[18]	N=120 (healthy, 77 females), mean age 21.6 yr. Double-blind, randomized, parallel groups study. 25g glucose drink or placebo (30mg saccharine).	VAS scales on alert, overall mood and also hungry and thirsty 20min and after completing cognitive tasks	Main effect of time ($F(1,117)=40.96$, $p<0.001$) on alertness, but no differential effect of glucose vs. placebo.

Markus (2007)[8]	N=37 (8 males, 29 females), age range 18-25 yr. Double-blind, placebo-controlled, counterbalanced, cross-over study. Carbohydrate-rich orange drink with high glucose content (2x200 ml, 184 kJ/100ml) or sweetened orange juice without glucose (2x200 ml, 0.3 kJ/100 ml)	POMS, before and during cold pressor stress	High glucose drink positively influenced mood under stress: increased feelings of vigor (p=0.005) and less fatigue.
Scholey and Fowles. (2002)[17]	N=45 (10 males, 35 females), mean age 22.6 ± 6.5 yr. Parallel groups, randomized, double-blind, placebo controlled study Glucose (25g), alcohol (2.9g saccharine + 0.38g/kg ethanol) or placebo (2.9g saccharine)	POMS, before and 45min after the drink	No differential effects of the drinks on mood scores.
Green et al. (2001)[7]	N=26 (healthy individuals), age range: 18-40 yr. Cross-over study: five test-sessions Glucose drink (50g) or placebo drink (aspartame).	14 VAMS (100mm) before and 30min after the drinks and cognitive testing	Three-way interaction for ratings of 'dejected' (p=0.016). At baseline the score for dejection differed between sessions: subjects expected and received glucose vs. subjects expected glucose, but received placebo (p<0.05). Overall decrease in 'energetic' at each test session (p=0.026).
Owens et al. (1997)[15]	3 Parallel, random, double-blind experiments: <u>Experiment 1</u>: N=96 (48 males, 48 females), mean age 22.4 ± 5.4 yr. <u>Experiment 2</u>: n=50 (males), mean age 21.7 ± 4.9 yr. <u>Experiment 3</u>: N=70 (females), mean age 21.5 ± 4.8 yr. Glucose (50g) or placebo drink	AD-ACL <u>Experiment 1</u>: before and 15 & 35min after the drink and frustrating computer game <u>Experiment 2</u>: before and 20 after the drink and after 35, 45, 55, 65 min during the Stroop task and at last	Significant relations between falling blood glucose and decreases in self-reported energy, following the completion of all 3 cognitively demanding tasks.

	(aspartame and acesulfame K) and 20 min later a 2nd drink of glucose (25g) or placebo (in experiment 2 and 3 only).	after the Stroop task Experiment 3: before and 20 min after the drink and after RIPT	
Benton and Owens. (1993)[14]	3 Parallel, random, double-blind experiments: Experiment 1: N=354 (157 males, 197 females), mean age 21.7 ± 4.9 yr. Experiment 2: N=53 (females), mean age 21.5 ± 5.0 yr. Experiment 3: N=96 (48 males, 48 females), mean age 22.4 ± 5.4 yr. Glucose (50g) or placebo drink (aspartame and acesulfame K) and in experiment 2 + 2nd & 3rd glucose drink (25g each) 45 & 75min later or 3 placebo drinks	AD-ACL and 6 VAMS scales (in experiment 3 only) Experiment 1: before and either 15 or 30min after drinks Experiment 2: before and 30, 60 & 115min after drinks Experiment 3: before and 15min after drinks and after frustrating computer game	A glucose drink in the morning and higher blood glucose levels were both associated with feeling less tense in all 3 experiments and with fewer negative responses in the frustrating situation. In the 1st experiment higher blood glucose was also borderline correlated with greater self-reported energy (r=0.09, p<0.056). The other mood measures did not change.

Abbreviations: AD-ACL: Activation-Deactivation Adjective Check List, 30-item mood questionnaire; h: hour; min: minutes; PANAS: Positive and Negative Affect Schedule; POMS: Profile of Mood States, 65 self-report items; POMS-SF: Profile of Mood States – Short Form, 37 item version of the POMS; RIPT: Rapid Information Processing Task; TMD: Total Mood Disturbance, can be calculated from POMS or POMS-S; VAMS: Visual Analogue Mood Scale; vs.: versus; yr: year.

Table 3 **Overview of studies investigating the effect of sucrose compared to placebo on mood**

Reference	Population and study design	Mood measure	Results
van der Zwaluw et al. (2014)[4]	N=43 (older men and women with self-reported memory complaints), age ≥70 yr, mean	POMS-SF, t=0 min (before drink) & t=90min, in cognitive demanding	After sucrose vs. placebo negative emotions were higher at t=90 (p=0.03 for depression and for tension).

	age: 77.7 ± 5.6 yr. Cross-over study: three 1-day test trials with 1-week washout period Glucose drink (50g), sucrose drink (100g), placebo (artificial sweetener)	situation	Lower vigor score at t=0 min (p=0.02) and at t=90 (p=0.05) and worse depression score at t=0 (p=0.02) after sucrose compared to glucose.
Reid et al. (2010)[27]	N=53 (women with BMI between 25-30kg/m^2), age range 20-55 yr, mean age ≈ 34 yr. 4-week parallel study Daily sucrose sweetened Irn-Bru (4x250 ml, 180 kJ/100ml) vs. aspartame-sweetened Irn-Bru (4x250 ml, 17 kJ/100ml)	Diary with ten 80mm VAMS, directly after the drinks, i.e. daily at 11.00, 14.00, 16.00 and 20.00h	The sucrose drink vs. the placebo drink had no significant effect on mood ratings. Mood scores varied significantly as function of time of day.
Reid et al. (2007)[28]	N=133 (normal weight women), age range: 20-55 yr, mean age 31.8 ± 9.1 yr. 4-week parallel study Sucrose-sweetened Irn-Bru vs. diet aspartame sweetened Irn-Bru	Diary with 10 VAMS, directly after the drinks, i.e. daily at 11.00, 14.00, 16.00 and 20.00h	Mood scores varied significantly as function of time of day, but no effect of sucrose drink vs. diet drink on mood scores.
Reid & Hammersley (1998)[26]	N=90 (45 obese and 45 non-obese women), mean age 33.2 ± 7.8 and 34.9 ± 8.2 yr. Between-subjects, blind design Sucrose drink (40g) vs. 2 alternative placebos: saccharin and water	POMS-BI, before, directly after and 30min after the drinks	Mood was not differentially affected by sucrose vs. the placebo drinks. Women with a high drive for thinness tended to rate themselves as more clearheaded 30min after any preload, trend for feeling less clearheaded directly after sucrose drink not significant.
Reid &	N=60 (31 males, 29 females),	POMS, before, directly	No effect of sucrose on mood immediately or after 30

Hammersley (1995)[25]	age range 18-55 yr. Between-subjects, blind placebo design Sucrose drink (40g) vs. placebo (saccharin; blind control) or water (unblind control)	after and 30 & 60min after the drinks	or 60min of intake. Only increase in energy at 30 min in 2/4 females, i.e. small effect.
Pivonka (1990)[23]	N=120 (women) Age range 18-30 yr, mean age 20.0 ± 0.2 yr. Cross-over study Sugar-sweetened (50g sucrose/12oz), aspartame-sweetened (180-280mg/12oz) and unsweetened Kool-Aid	SSS, VAMS, and POMS directly and 30 & 60min after the drinks	Increased sleepiness after the sugar-sweetened beverage vs. the 2 controls ($p<0.02$ after 30min and $p<0.005$ after 1hr). Mood states not significantly different.
Brody & Wolitzky (1983)[24]	N=53, age range 16-24 yr, mean age 18.7 yr. Parallel study Sucrose solution (100g), saccharin solution or water	NIMH mood scale before and 20min and 4h after the drinks	No significant effect on mood after sucrose ingestion compared to saccharin or water.

Abbreviations: BMI: Body Mass Index (kg/m^2); h: hour; Irn-Bru: carbonated Scottish soft drink; min: minutes; NIMH: National Institute of Mental Health mood scale; POMS: Profile of Mood States, 65 self-report items; POMS-BI: Bipolar form of the Profile of Mood States; POMS-SF: Profile of Mood States – Short Form, 37 item version of the POMS; SSS: Stanford Sleepiness Scale; VAMS: Visual Analogue Mood Scale; vs.: versus; yr: year.