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Association between dietary saccharide intake and self-reported memory performance in middle-aged adults

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The aims of the present study were to assess dietary intake of saccharides in middle-aged adults, and to determine whether intakes of these sugar nutrients were related to self-reported memory performance. A population-based sample of 1183 men and women (aged 40–60 years) completed questionnaires assessing everyday memory function. Dietary intake status of saccharides was estimated using a self-completed, quantified FFQ. After controlling for demographic and health measures (for example, time spent exercising, smoking and alcohol consumption), saccharide intake was related to better self-reported memory functioning. Thus, longer-term intakes of saccharides through the usual diet may be positively related to perceived memory performance in mid-life.

Dietary intake: Saccharides: Memory: Mid-life

The impact of nutrition on aspects of health and psychological state, including cognition, is gaining increasing scientific interest[1]. A growing body of literature has shown positive effects of specific nutrients, including folate, vitamins B_6 and B_{12}, thiamin, niacin, Zn, Fe, antioxidants, fatty acids and amino acids on cognitive performance[2–4], indicating that nutrition can influence brain functioning and cognition. More recently, emerging research suggests potential benefits of saccharides to cognition[5].

Saccharides are biological sugars that are essential for the healthy functioning of the body and brain[6–8]. They are found in plants, primarily fruit and vegetables, such as radishes, leeks, mushrooms, asparagus, apples and pears[9]. In the brain, saccharides are involved in the proper functioning of synapses and neurotransmitters and therefore the electrical activity of neurons[10,11] as well as the integrity of the central nervous system in general[12]. Hence, because of this wide-ranging role of saccharides in brain function, saccharides are likely to affect a broad array of cognitive abilities. Of the over 200 known saccharides, glucose has been the most widely researched. Although glucose is not invariably linked to enhanced cognition, several studies have demonstrated positive effects of this monosaccharide on cognitive performance, with stronger effects found for performance on tasks of memory compared with other cognitive functions[13–18].

Accumulating evidence from supplementation studies in animals and human subjects suggests that other saccharides, in particular the polysaccharides fucose, mannose, galactose, rhamnose, arabinose and xylose, may also be linked to improved cognition. In particular, administration of fucose for several days has been shown to enhance hippocampal function and improve memory performance in chicks and rats[19–21]. Additionally, injections of fucose, mannose and galactose to the brain over a period of 30 d have been found to improve spatial learning in rats[22].

In human subjects, the research is limited. Single case reports provide further evidence for positive effects of saccharides on cognition. For example, fucose supplementation over 9 months administered by gastrointestinal tube improved speech and language abilities of a young child with leucocyte adhesion deficiency type II[23]. In addition, supplementation with a combination of saccharides, including fucose, galactose, mannose, arabinose and xylose, over 4 weeks improved the cognitive abilities, including retrieval from short-term memory, of an 8-year-old boy with dyslexia[24]. Furthermore, a 5-week supplementation of these saccharides in clinically diagnosed alcoholics showed a trend towards improvement in self-reported cognition[25]. Further, single-dose oral ingestions of the same combination of saccharides increased brain activity, as measured by electroencephalograph, and was associated with a trend towards improved performance on tasks of attention in a non-clinical sample of young adults[26,27]. Finally, a single-dose oral ingestion of a combination of saccharides produced better scores on tasks of memory than a placebo in healthy middle-aged adults, although this difference was not statistically significant[28].

The absence of statistically significant short-term effects of the aforementioned polysaccharides on cognitive performance may be because of their role in the brain. Specifically, unlike glucose, these saccharides are thought to play a long-term

Abbreviation: MFQ, memory functioning questionnaire.
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structural and functional role in the brain, such as the development and function of neuronal membranes and synaptic junctions[5]. As a result, any saccharide effects on cognition are likely to be subtle and may only become apparent following intake over longer periods of time. In support, a recent longitudinal study[29] found that over a 6-year period, consumption of vegetables such as zucchini, eggplant, broccoli and lettuce, which are thought to be rich sources of saccharides, was associated with slower rates of cognitive decline in older adults. Assessment of usual saccharide intake in the diet presents a non-invasive procedure for examining potential longer-term effects of saccharide intake. Indeed, a recent investigation of dietary saccharide intake and cognitive performance in middle-aged adults found that a higher intake of saccharides was related to better verbal memory performance[30]. However, the study was limited by the nature of the assessment of saccharide intake, which was estimated from the number of servings of certain vegetables and fruit believed to be rich in saccharides.

Thus, the present study aimed to determine intake of saccharides more accurately using detailed assessment of dietary saccharide intake in a large, population-based sample of middle-aged adults and examined whether intake was related to self-reports of memory performance. To our knowledge, the present study is the first to provide a comprehensive estimate of saccharide intake in adults. Middle-aged individuals were chosen because the first signs of age-associated cognitive decline often become apparent in mid-life[31,32].

Methods

Participants

Participants were recruited through a letter of invitation sent to 2000 women and 2000 men randomly selected from the 40–60-year-old age band of the South Australian electoral rolls. As voting is compulsory in Australia, this random selection of potential participants is likely to closely approximate a random sample of the population. A total of 983 (23·66 %) volunteers expressed interest in participating and were sent two questionnaires to complete. Of these, 498 women and 333 men returned completed questionnaires, yielding a response rate of 84·54 % of those who volunteered. Further recruitment through media publicity resulted in another 478 volunteers, of whom 263 women and 123 men returned completed questionnaires, yielding a response rate of 80·75 %. The final sample of 1183 participants comprised 751 women and 432 men. Proficiency in English was the only exclusion criterion, as the questionnaires were language rich.

Measures

Self-report measures in questionnaire format were presented in two booklets. The first booklet contained questions relating to everyday memory function, as well as demographics and health. The second booklet contained a FFQ designed to assess usual dietary intake.

Memory performance. Perceived everyday memory function was assessed by the memory functioning questionnaire (MFQ)[33]. The MFQ provides an assessment of perceived memory functioning in non-clinical samples. It contains sixty-four items across seven domains which examine the presence of memory problems (one item, maximum score 7), the frequency of common memory problems (eighteen items, maximum score 126), the frequency of poor reading recall (ten items, maximum score 70), the quality of recall (four items, maximum score 28), the seriousness of forgetting (eighteen items, maximum score 126), retrospective functioning (comparison of current memory with past memory function; five items, maximum score 35), and the use of mnemonics (eight items, maximum score 56). Participants rated their responses on a seven-point scale ranging from 1 to 7. Across all domains, except use of mnemonics, higher scores represent higher levels of perceived memory functioning.

Demographics and health. Demographics and health measures included questions about age, years of education, self-rated health (rated 1 = poor to 5 = excellent), BMI calculated from self-reported height and weight using the formula weight/(height)^2, minutes of exercise (defined as sport) per week, number of cigarettes smoked per d, number of alcoholic (i.e. standard) drinks per week, number of on-going medical conditions, number of currently used medications and number of currently used dietary supplements. These variables have previously been shown to affect cognitive performance[34–36], and hence were examined as potential covariates of any associations between dietary intakes of fucose, mannose, galactose, rhamnose, arabinose and xylose, and self-reported memory performance.

Dietary intake. Dietary intake of saccharides was estimated using a self-completed, quantified FFQ[37]. This took the form of a twenty-page booklet including a list of over 180 common food and beverage items and questions relating to food preparation and dietary habits. Participants indicated how often they consumed each of the listed foods and beverages. Average daily consumption was based on participants' reports of how often a specified standard serving size of each food or beverage item was consumed. For example, intakes of fucose, mannose, galactose, rhamnose, arabinose and xylose were derived from food sources such as flaxseed, cauliflower, Brussels sprouts, legumes, red cabbage and husks of grain, respectively. This information, together with the nutrient composition of the food item per unit weight taken from food tables[38,39], allowed participants' daily nutrient intake to be calculated using the FREQUAN dietary analysis program. Such analyses have been shown to adequately capture habitual dietary patterns and to provide an indication of nutritional intake from the diet[40,41].

Design

A cross-sectional design was used to investigate the links between dietary intake of fucose, mannose, galactose, rhamnose, arabinose and xylose, and self-reported cognition. Intake was calculated as the total of soluble and insoluble amounts of each of these saccharides consumed (μg/d). The dose–response relationship between some nutrient intakes (for example folate, vitamins B_{12} and B_6) and cognition has previously been shown to be non-linear, with moderate intakes associated with better performance[42]. Hence, to be able to identify any non-linear effects of dietary saccharide intake on cognition, dietary intake quartiles for fucose, mannose, galactose, rhamnose, arabinose and xylose were used as the

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independent variables, with the first quartile reflecting the lowest intake and the fourth reflecting the highest.

Results

Before analysis, distributions of all variables were examined for normality. The data for all variables were normally distributed. ANOVA were conducted to identify demographics and health indicators that differed by fucose, mannose, galactose, rhamnose, arabinose and xylose intake quartiles for possible inclusion as covariates when assessing the effects of intakes on cognition. *Post hoc* comparisons using Bonferroni procedures were carried out to locate significant differences between intake quartiles, with α set at 0·05. Significant results for each of the saccharides along with descriptive statistics on demographic and health variables are presented in Table 1. Non-significant differences are not presented.

As can be seen in Table 1, there were significant effects of fucose, mannose, galactose, rhamnose, arabinose and xylose quartiles for demographic and health indicators. Specifically, *post hoc* comparisons showed that higher fucose intakes (fourth quartile) were related to smoking fewer cigarettes and consuming less alcohol than low intakes (first quartile), and being in better health compared with moderate intakes (second quartile). Higher intakes of mannose (third and fourth quartiles) were in addition related to having a lower BMI, spending more time exercising and using more dietary supplements than low intakes (first quartile). For galactose, higher intakes were related only to having better self-reported health and drinking less alcohol, with higher intakes of saccharides (fourth quartile) being related to consuming significantly less alcohol than low intakes (first quartile). Higher intakes (fourth quartile) of rhamnose were related to being older, exercising more, consuming less alcohol and being in better health than low intakes (first quartile). Higher intakes (fourth quartile) of arabinose in addition related to having experienced more years of education than low intakes (first quartile). Finally, for xylose, higher intakes (fourth quartile) related to more years of education, and consuming less alcohol than low intakes (first quartile). Therefore, these demographic and background variables that were associated with saccharide intake were used as covariates in the analyses that follow.

Analyses of covariance were performed to determine the effects of dietary intake of fucose, mannose, galactose, rhamnose, arabinose and xylose on self-reported memory performance. *Post hoc* comparisons using Bonferroni procedures were carried out to locate significant differences between intake quartiles, with α set at 0·05. Only significant results for each saccharide along with descriptive statistics are presented in Table 2. Additionally, regression analyses were carried out to determine the amount of unique variance in self-reported memory functioning explained by each of the saccharides after controlling for the specific covariates.

There were significant effects of fucose intake on the frequency of common memory problems and the mnemonics usage subscales of the MFQ, after controlling for time spent exercising, self-rated health, number of cigarettes smoked and number of alcoholic drinks. *Post hoc* comparisons showed that individuals in the first intake quartile reported more frequent memory problems than those in the second quartile. Individuals in the first intake quartile also reported using mnemonics more frequently than those in the second and third intake quartiles. Fucose intake still explained a significant 0·2 % of the variance in frequency of common memory problems and 0·3 % of the variance in mnemonic usage after controlling for the aforementioned covariates. After controlling for self-rated health, BMI, time spent exercising, number of cigarettes smoked, number of alcoholic drinks and number of dietary supplements, intake of mannose also had a significant effect on the mnemonics usage subscale of the MFQ, with those in the first intake quartile reporting more frequent use of mnemonics than those in the third intake quartile. Mannose intake contributed a further 1·2 % of the variance in mnemonic usage after prior entry of the covariates. Additionally, there were significant effects of galactose intake on the frequency of common memory problems, the frequency of poor reading recall and the retrospective functioning subscales of the MFQ after controlling for self-rated health and alcohol consumption. In particular, individuals in the first and second intake quartiles reported less frequent memory problems than those in the fourth quartile. Individuals in the second intake quartile also compared their current memory more favourably to past memory function than did those in the fourth intake quartile, and reported less frequent poor reading recall than those in the third and fourth intake quartiles. Galactose intake accounted for a further 1·2 % of the variance in frequency of common memory problems, 0·7 % of the variance in frequency of poor reading recall, and 0·7 % of the variance in retrospective functioning beyond that accounted for by the covariates. Furthermore, there were significant effects of rhamnose intake on the mnemonic usage subscale of the MFQ after controlling for age, time spent exercising, number of alcoholic drinks and self-rated health. Specifically, individuals in the first quartile self-reported greater use of mnemonic strategies for memory than those in the second and third quartiles. Rhamnose intake explained an additional 1·3 % of the variance in mnemonic usage over and above that explained by the covariates. Finally, there were no statistically significant effects of xylose on any memory measure, and there was a non-significant trend for an effect of arabinose on mnemonic usage ($P=0·06$).

Discussion

The present study assessed the dietary intake of saccharides in middle-aged adults, and examined whether intake was associated with self-reported memory performance. At present there is no recommended daily intake for saccharides. To our knowledge, the present study is the first to report quantified dietary intakes of the saccharides fucose, mannose, galactose, rhamnose, arabinose and xylose, in a population-based sample. Intakes of these saccharides were positively related to indicators of health, such as exercise, smoking and alcohol consumption. This suggests that individuals with higher intakes of saccharides tend to also have other healthy lifestyle habits.

Dietary intakes of fucose, mannose, galactose and rhamnose were related to self-reported memory functioning. In particular, saccharide intake was related to perceived frequency of memory problems, reading recall, retrospective functioning

Table 1. Demographic and health measures by saccharide intake quartile
(Mean values and standard deviations)

	Saccharide intake quartiles								
	0–25 %		25–50 %		50–75 %		75–100 %		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F(3, 1183)
Fucose									
n	270		388		218		307		
Intake (µg/d)	0·005	0·004	0·024	0·004	0·044	0·006	0·085	0·039	
Range of intake (µg/d)	0·00–0·01		0·02–0·03		0·04–0·06		0·07–0·32		
Demographic and health measures									
Self-rated health	3·21^{a,b}	1·02	3·17^{b}	1·05	3·32^{a,b}	0·94	3·41^{a,c}	0·96	6·49*
Number of cigarettes smoked (per d)	3·59^{a}	8·83	2·29^{a,b}	7·07	1·61^{a,b}	6·05	1·14^{b}	5·39	3·78*
Number of alcoholic drinks (per week)	7·49^{a}	13·26	6·33^{a,b}	9·81	5·68^{a,b}	8·29	4·82^{b}	6·56	3·69*
Mannose									
n	298		293		294		298		
Intake (µg/d)	0·35	0·079	0·54	0·037	0·69	0·054	1·00	0·207	
Range of intake (µg/d)	0·13–0·47		0·48–0·61		0·62–0·80		0·81–1·94		
Demographic and health measures									
BMI (kg/m^2)	27·40^{a}	5·12	26·48^{a,b}	5·09	26·03^{b}	4·27	26·06^{b,c}	4·27	5·24**
Self-rated health	3·10^{a}	1·05	3·26^{a,b}	1·01	3·41^{b}	0·93	3·31^{b,c}	1·02	5·31**
Exercise time (min)	157·48^{a}	180·77	210·21^{a,b}	218·96	218·96^{b}	200·60	220·50^{b,c}	173·05	5·41**
Number of cigarettes smoked (per d)	3·16	8·10	2·42	7·03	1·73	6·65	1·34	5·99	4·18**
Number of alcoholic drinks (per week)	7·94	12·67	6·02	8·44	6·08	10·27	4·29	6·42	6·93**
Number of dietary supplements	0·99	1·62	0·93	1·59	0·98	1·41	1·36	1·77	4·91**
Galactose									
n	296		296		295		296		
Intake (µg/d)	1·14	0·201	1·60	0·113	1·97	0·114	2·75	0·529	
Range of intake (µg/d)	0·44–1·40		1·41–1·79		1·79–2·20		2·21–5·93		
Demographic and health measures									
Self-rated health	3·18	1·01	3·20	1·00	3·34	0·99	3·36	1·01	3·33*
Number of alcoholic drinks (per week)	7·60^{a}	12·36	5·85^{a,b}	8·17	5·62^{a,b}	8·24	5·26^{b}	9·74	2·62*
Rhamnose									
n	292		304		291		296		
Intake (µg/d)	0·15	0·037	0·23	0·019	0·30	0·022	0·45	0·106	
Range of intake (µg/d)	0·04–0·21		0·22–0·27		0·28–0·35		0·36–1·04		
Demographic and health measures									
Age (years)	49·91^{a}	5·64	50·43^{a,b}	6·08	50·60^{a,b}	5·99	51·60^{b}	5·31	4·42**
Self-rated health	3·16^{a}	1·02	3·22^{a,b}	1·02	3·27^{a,b}	0·97	3·43^{b}	0·98	4·01**
Exercise time (min)	169·52^{a}	193·73	194·92^{a,b}	189·58	208·36^{a,b}	182·62	234·80^{b}	209·61	4·86**
Number of alcoholic drinks (per week)	7·37^{a}	12·65	5·96^{a,b}	8·37	6·13^{a,b}	7·58	4·89^{b}	9·80	3·17*
Arabinose									
n	295		301		290		297		
Intake (µg/d)	2·18	0·41	3·13	0·22	4·00	0·28	5·70	1·07	
Range of intake (µg/d)	0·78–2·76		2·77–3·54		3·55–4·55		4·56–11·24		
Demographic and health measures									
Age (years)	49·85^{a}	5·86	50·95^{a,b}	5·80	50·38^{a,b}	5·80	51·36^{b}	5·61	3·84**
Length of education (years)	12·79^{a}	3·43	13·36^{a,b}	3·67	13·10^{a,b}	3·56	13·67^{b}	3·99	3·00*
Self-rated health	3·15^{a}	1·02	3·25^{a,b}	0·98	3·28^{a,b}	1·00	3·40^{b}	1·00	3·12*
Exercise time (min)	167·28^{a}	197·14	2174·38^{a,b}	214·09	193·94^{a,b}	158·83	230·44^{b}	199·42	4·95**
Number of cigarettes smoked (per d)	3·14	8·20	2·02	6·10	1·79	6·71	1·71	6·83	2·62*
Number of alcoholic drinks (per week)	7·52^{a}	12·73	6·41^{a,b}	8·30	5·93^{a,b}	10·13	4·47^{b}	6·91	4·98**
Xylose									
n	294		297		296		296		
Intake (µg/d)	2·03	0·42	3·09	0·24	4·05	0·35	6·04	1·26	
Range of intake (µg/d)	0·64–2·67		2·68–3·55		3·56–4·74		4·75–12·38		
Demographic and health measures									
Length of education (years)	12·53^{a}	3·28	13·51^{a,b}	3·81	13·19^{a,b}	3·36	13·69^{b}	4·12	5·66**
Number of cigarettes smoked (per d)	3·01	7·94	1·80	6·22	2·35	7·43	1·50	6·25	2·64*
Number of alcoholic drinks (per week)	7·36^{a}	12·55	6·36^{a,b}	10·03	6·20^{a,b}	8·82	4·41^{b}	6·73	4·67**

^{a,b,c}Mean values within a row with unlike superscript letters were significantly different ($P<0·05$).
*$P<0·05$, **$P<0·01$.

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Table 2. Memory functioning by saccharide intake quartile
(Mean values and standard deviations)

	Saccharide intake quartiles								
	0–25 %		25–50 %		50–75 %		75–100 %		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*F*(3, 1183)
Fucose									
n	270		388		218		307		
Intake (μg/d)	0·005	0·004	0·024	0·004	0·044	0·006	0·085	0·039	
Range of intake (μg/d)	0·00–0·01		0·02–0·03		0·04–0·06		0·06–0·32		
Memory measures									
Frequency of common memory problems	91·72[a]	16·14	95·00[b]	13·33	92·92[a,b]	14·97	95·26[a,b]	13·48	3·86**
Mnemonic usage	29·29[a]	9·90	27·16[b]	10·52	26·18[b,c]	10·39	27·51[a,b,c]	10·35	2·98*
Mannose									
n	298		293		294		298		
Intake (μg/d)	0·35	0·079	0·54	0·037	0·69	0·054	1·00	0·207	
Range of intake (μg/d)	0·13–0·47		0·47–0·61		0·61–0·80		0·80–1·94		
Memory measure									
Mnemonic usage	28·75[a]	10·15	26·94[a,b]	10·12	25·84[b]	9·75	26·94[a,b]	10·67	2·56*
Galactose									
n	296		296		295		296		
Intake (μg/d)	1·14	0·201	1·60	0·113	1·97	0·114	2·75	0·529	
Range of intake (μg/d)	0·44–1·40		1·41–1·79		1·79–2·20		2·20–5·93		
Memory measures									
Frequency of common memory problems	94·51[a]	15·15	95·61[a]	12·93	93·82[a,b]	14·44	91·90[b]	14·66	4·72**
Frequency of poor reading recall	55·57[a,b,c]	11·73	57·14[a]	10·41	55·33[b]	11·25	55·10[b,c]	10·15	2·68*
Retrospective functioning	23·12[a,b]	6·99	23·85[a]	6·65	23·64[a,b]	6·72	22·54[b]	6·96	2·87*
Rhamnose									
n	292		304		291		296		
Intake (μg/d)	0·15	0·037	0·23	0·019	0·30	0·022	0·45	0·106	
Range of intake (μg/d)	0·04–0·21		0·22–0·27		0·28–0·35		0·36–1·04		
Memory measure									
Mnemonic usage	29·14[a]	0·67	26·51[b]	0·64	26·02[b,c]	0·65	27·63[a,b,c]	0·64	4·39**

[a,b,c] Mean values within a row with unlike superscript letters were significantly different ($P<0·05$).
* $P<0·05$, ** $P<0·01$.

and mnemonics usage. Thus, longer-term intakes of saccharides through the usual diet appear to be positively related to memory functioning. The observed associations between usual dietary intakes of fucose, mannose, galactose, rhamnose and memory functioning are consistent with reports of enhanced learning and memory in animals following supplementation with these saccharides[20,22,43], and accord with the proposed mechanism of saccharide effects in the brain. In particular, saccharides have been shown to specifically enhance the cellular mechanism required for the formation of memory traces in hippocampal cells[19]. The present findings also concur with a recent study that found positive effects of saccharide intake, estimated from the consumption of saccharide-containing vegetables and fruit, on verbal recall[30].

Overall, moderate intakes of fucose, mannose, galactose and rhamnose (i.e. second and third intake quartiles) were associated with better self-reported memory performance. This suggests that the relationship between saccharide intake and cognition may be non-linear, and would concur with previous reports of non-linear dose–response relationships between various nutrients (for example, folate and B vitamins) and cognitive performance[3,42]. Importantly, self-rated memory did not decline, but rather plateaued, at higher saccharide intake levels. Morris *et al.* [29] similarly showed minimal differences in rates of cognitive change between the fourth and fifth intake quintiles of vegetable intake.

Intakes of fucose, mannose, galactose and rhamnose continued to explain a significant, albeit small, proportion of the variance in self-reported memory performance after controlling for demographic and health measures, such as exercise, smoking and alcohol consumption. This suggests that dietary saccharide intake contributes to perceived memory functioning over and above any influence of healthy lifestyle indicators. However, because of the complex interactions between nutrients in foods, the present findings could also reflect antioxidant effects. Hence, the present findings need to be followed by randomised controlled intervention studies that allow for greater control over the amount of saccharides consumed and to establish any causal link between saccharide intake and memory functioning.

A potential limitation of the present study is the use of self-report measures to assess memory functioning. Not only do individuals have difficulty accurately judging their cognitive abilities[44,45], but self-report measures are also prone to social desirability response biases. In addition, correlations between self-report and objective measures of memory are at best moderate[46,47]. Thus, future investigations into the relationship between dietary saccharide intake and memory might usefully employ more objective indices of memory performance, such as the Wechsler memory scales[48] and the Rey auditory-verbal learning test[49].

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