Blood pressure responses in healthy older people to 50 g carbohydrate drinks with differing glycaemic effects

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The aim of the present study was to determine the effects on blood pressure response of 50 g carbohydrate drinks with differing glycaemic effects in ten healthy elderly subjects (age >65 years; randomized crossover design). Systolic (SBP), diastolic (DBP) and mean arterial (MAP) blood pressure, heart rate and plasma glucose levels were determined following ingestion of equal volumes (379 ml) of water and 50 g carbohydrate drinks with differing reported glycaemic indices (GI) (surrogate marker for glycaemic effect): (1) low-GI: Apple & Cherry Juice; (2) intermediate-GI: Fanta Orange; (3) high-glucose. Glucose (SBP and DBP $P<0.001$; MAP $P=0.005$) and Fanta Orange (SBP $P=0.005$; DBP and MAP $P<0.001$) ingestion caused a significant decrease in BP whilst blood pressure increased (SBP $P=0.008$; MAP $P=0.005$) from baseline following Apple & Cherry Juice ingestion. Water had no significant effect on postprandial blood pressure. Fanta Orange and Apple & Cherry Juice caused similar ($P=0.679$) glycaemic effects, which were significantly greater than water, but lower than glucose ($P<0.001$). There was no significant correlation between the glycaemic effect of the carbohydrate drinks and there was no change in blood pressure from baseline (SBP r -0.123, $P=0.509$; DBP r -0.051, $P=0.784$; MAP r -0.069, $P=0.712$). Apple & Cherry Juice and Fanta Orange had similar glycaemic effects, but differing effects on blood pressure. Therefore, it is unlikely that the glycaemic effect of a drink can be used to predict the subsequent cardiovascular response.

Glycaemic effect: Blood pressure: Elderly

Blood pressure (BP) normally decreases after a meal and reaches a nadir between 30 to 60 min after eating (Jansen & Lipsitz, 1995; Smith *et al.* 2003). When excessive, this decrease is termed postprandial hypotension (PPH), defined as a decrease in systolic BP ≥ 20 mmHg within 2 h of the start of a meal. PPH is associated with an increased incidence of falls, syncope, angina and transient ischaemic attacks, particularly in older people and patients with autonomic neuropathy (most frequently due to diabetes mellitus) (Mathias *et al.* 1989; Jansen & Lipsitz, 1995). PPH is a relatively common, but under-recognized, problem in older people. For example, in a study of 499 older residents, ambulatory or wheelchair-bound, in a long-term healthcare facility, 24 % were found to have PPH, with significantly greater postprandial BP decreases occurring in those who had experienced falls or syncope in the preceding 6 months than in those who had not (Aronow & Ahn, 1994).

The pathophysiology of PPH is poorly understood, but it is likely to be multifactorial (Jansen & Lipsitz, 1995). The magnitude of the postprandial BP fall is dependant on meal composition. Ingestion of carbohydrates, particularly glucose and to a lesser degree starch, but not fructose or xylose, lowers BP more than ingestion of protein, fat or water (Mathias *et al.* 1989; Jansen *et al.* 1990; Heseltine *et al.* 1991; Jansen & Lipsitz, 1995; Robinson & Potter, 1995). Guar, a naturally occurring, non-absorbed, gel-forming carbohydrate of vegetable origin has been shown to attenuate the fall in BP seen following the ingestion of a glucose drink (Jones *et al.* 2001). Thus, modification of meal composition could provide a means of reducing excessive postprandial BP falls in people with PPH.

A revised list of the relative glycaemic indices (GI) of different foods was recently published by Foster-Powell *et al.* (2002). Foods with a high GI produce a higher peak (per g carbohydrate) in postprandial blood glucose and a greater overall blood glucose response during the first 2 h after consumption, reflecting a greater glycaemic effect than foods with a low GI. The GI is calculated by measuring the incremental area under the capillary blood glucose curve following ingestion of a test meal providing 50 g carbohydrate, compared with the area under the capillary blood glucose curve following an equal carbohydrate intake from the reference meal (glucose drink or bread) multiplied by 100. Foods are classified as having a low (<55), intermediate ($55-69$), or high (≥ 70) GI.

The addition of guar to a glucose drink reduces its glycaemic effect: adding 14·5 g guar to a 50 g glucose drink reduces its GI from 100 (arbitrarily designated) to 62 (Foster-Powell *et al.* 2002). This reduction in glycaemic effect could be a mechanism by which it attenuates the fall in BP (Jones *et al.* 2001). We therefore hypothesized that the lower the glycaemic effect of a food, the smaller the postprandial reduction in BP. If so, it may be possible to design diets for people with PPH based on the glycaemic effects of food using published GI values of foods as a surrogate marker.

The purpose of the present study, therefore, was to determine the effects of drinks with equal volume and carbohydrate content, but differing glycaemic effects, on postprandial BP.

Methods

Subjects

Healthy subjects (six male, four female), aged 65–77 (mean 71·30 (SEM 1·38) years) and mean BMI 26·69 (SEM 0·82) kg/m^2, were recruited by advertisement. All subjects were non-smokers and had no history of gastrointestinal disease or surgery, diabetes mellitus, significant respiratory or CVD, chronic alcohol abuse, epilepsy or symptoms of autonomic dysfunction. No subject was taking any medication known to influence BP and all medications remained unchanged during the study.

Protocol

Each subject had BP, heart rate (HR) and plasma blood glucose measurements taken on four separate study days before and after ingestion of one of the study drinks (described later), in random order. The studies were not blinded and were separated by at least 72 h. All drinks were consumed within 3 min and served at 22°C to avoid the potential effect of temperature on BP (Kuipers *et al.* 1991). The carbonated drink (Fanta Orange) was allowed to stand for 20 min to reduce carbonation. Subjects attended the Department of Medicine following an overnight fast (10 h for solids and 6 h for liquids), at the same time (08.30 hours) for all studies. The study room was air-conditioned with the temperature set at 22 ± 3°C. A cannula was placed in the left antecubital vein for blood sampling and subjects were seated comfortably in a chair to mimic normal physiological conditions during a meal. A BP cuff was attached to the right upper-arm. Cardiovascular autonomic function was evaluated on one of the study days. Each subject gave written, informed consent and the study was approved by the Research Ethics Committee of the Royal Adelaide Hospital.

Study drink

The study drinks were selected based on their predicted glycaemic effect using the GI as a surrogate marker (Foster-Powell *et al.* 2002). The commercially available drinks (Fanta Orange and Apple & Cherry Juice) were manufactured in Australia and bought from the local supermarket.

(1) 50 g glucose (GI 100: arbitrarily designated) in 359 ml water and 20 ml bottled lemon squeeze (Berri Ltd, Victoria, Australia; 99·9% lemon juice with 25 mg carbohydrate/l);
(2) 368 ml Fanta Orange, a commercially available carbonated drink manufactured by Coca Cola (Coca Cola Amatil, Sydney, New South Wales, Australia; reported intermediate GI 68 (SEM 6) (Foster-Powell *et al.* 2002)), plus 11 ml water;
(3) 379 ml Apple & Cherry Juice, a commercially available preservative-free fruit juice (Wild about Fruit Company Pty Ltd, Wandin, Victoria, Australia; reported low GI 43 (SEM 3) (Foster-Powell *et al.* 2002));
(4) 379 ml water (control drink).

Measurements

Blood pressure and heart rate. BP (systolic (SBP), diastolic (DBP), mean arterial (MAP) pressure) and HR were measured using an automated oscillometric BP monitor (DINAMAP ProCare; GE Medical Systems, Rydalmere, New South Wales, Australia). Following a 20 min rest after cannula insertion, three measurements were obtained at 9, 6 and 3 min before drink ingestion at *t* 0. The mean value of these three readings formed the baseline value. Following ingestion of the drink, BP and HR measurements were measured every 3 min for the first 60 min (to *t* 60).

Plasma glucose measurements. Venous blood was obtained from the intravenous cannula for glucose estimation at baseline and *t* 15, 30, 45 and 60 min and stored in tubes containing fluoride and K-EDTA. These samples were than centrifuged for 15 min at 4000 rpm before being processed on an Olympus 5400 analyser using the hexokinase method at the Institute of Medical and Veterinary Science (Adelaide, South Australia, Australia).

Cardiovascular autonomic function. Autonomic nerve function was evaluated using standardized cardiovascular reflex tests (Ewing & Clarke, 1982; Piha, 1991). Parasympathetic function was evaluated by the variation (R–R interval) of the HR during deep breathing and the response to standing ("30: 15"). Sympathetic function was assessed by the fall in systolic BP in response to standing. Each of the test results was scored according to age-adjusted predefined criteria as: normal 0, borderline 1, abnormal 2, for a total maximum score of 6. A score ≥ 3 was considered to indicate autonomic dysfunction (Ewing & Clark, 1982; Piha, 1991).

Analyses

Carbohydrate content analysis. An analysis of the carbohydrate content of the Apple & Cherry Juice and Fanta Orange was undertaken by Health Sciences and Nutrition Division of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Adelaide,

South Australia, Australia. Sugars were extracted using aqueous ethanol (500 ml ethanol/l), as described in Association of Official Analytical Chemists' method 982.14, and quantified by HPLC using a pump (GBC Scientific Equipment Pty Ltd, Melbourne, Victoria, Australia) and refractive index detector, and a polyamine-bonded polymeric gel column from Astec (Advanced Separation Technologies Inc., Whippany, NJ, USA). Acetonitrile–water (75:25, v/v) was used as the mobile phase.

Statistical analysis. All values are expressed as means with their standard errors. Two-way repeated measures ANOVA was used to examine the overall effects of time and drink type (treatment) and the treatment × time interaction on the change in cardiovascular and plasma glucose measurements from baseline. When a treatment effect was seen, *post hoc* analysis using the Bonferroni–Dunn adjustment was performed. One-way repeated measures ANOVA were conducted to evaluate the effects of the drink type on BP, HR and plasma glucose measurements over the first 60 min. The correlation between BP response at time *t* (min; mean value of measurements from *t* 30–60, as the nadir in blood pressure measurements is known to be reached in this time; Jansen & Lipsitz, 1995) and the individual area under the plasma glucose curve (first 60 min) calculated by the trapezoidal method for each carbohydrate drink for each subject, was evaluated by the Spearman correlation analysis (i.e. combined analysis of thirty (ten subjects × three study days) values for each cardiovascular variable). All analyses were performed using Statview (version 5.0; Abacus Concepts, Berkeley, CA, USA) and SuperANOVA (version 1.2, Abacus Concepts, Berkeley, CA, USA). *P* values <0·05 were considered statistically significant.

Results

All subjects consumed the four drinks within the allocated time. No side effects related to the study were reported. The mean score for autonomic dysfunction was 0·9 (SEM 0·31) (range 0–3). One subject had sub-clinical autonomic dysfunction (score 3) without overt symptoms and so was not excluded from the study.

Carbohydrate content analysis

Approximately 50 % of the total carbohydrate content of the Apple & Cherry Juice was fructose, 30 % glucose and 21 % sucrose. In Fanta Orange, 45 % of the total carbohydrate content was fructose, 45 % glucose and 10 % sucrose.

Plasma glucose

Plasma glucose concentrations are shown in Fig. 1. There was no significant difference in the baseline plasma glucose values between the four study days.

There were significant treatment effects of drink type (*F* 45·326, *P*<0·001), time (*F* 26·495, *P*<0·001) and treatment × time effects (*F* 16·465, *P*<0·001) on plasma glucose values over the first 60 min. Glucose (*F* 24·790, *P*<0·001), Fanta Orange (*F* 15·716, *P*<0·001) and Apple & Cherry Juice (*F* 14·008, *P*<0·001) ingestion resulted
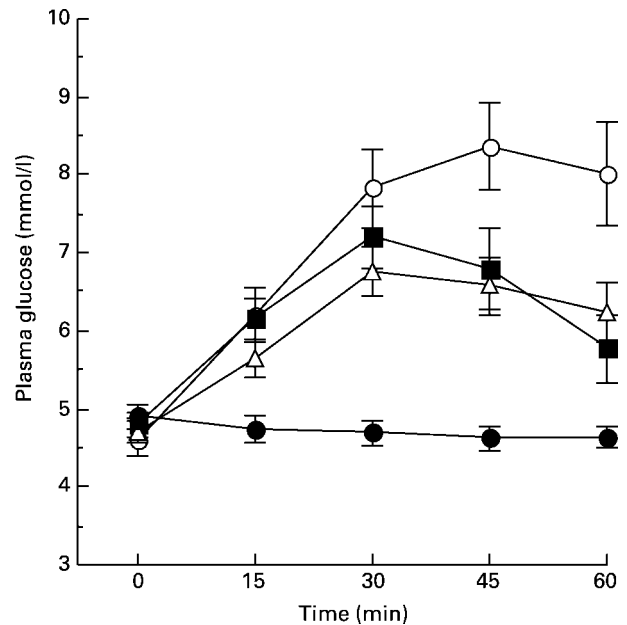

Fig. 1. The change in plasma glucose values (mmol/l) over 60 min following the ingestion of four different test drinks in ten healthy older people. ○, Glucose; ■, Fanta Orange; △, Apple & Cherry Juice; ●, water. For details of subjects, drinks and procedures, see p. 336. Values are means with their standard errors shown by vertical bars.

in a significant increase in plasma glucose measurements over the first 60 min. Glucose concentrations were similar after Apple & Cherry Juice and Fanta Orange (*P*=0·679), with glucose concentrations after both significantly higher than after water, but significantly lower than after glucose (*P*<0·001).

Blood pressure

Fig. 2(A, B, C) shows the changes in BP from baseline during the 60 min after drink ingestion. Fig. 3 shows the change in BP measurements from baseline at time *t* (mean of *t* 30–60). There was no significant difference in the baseline BP (SBP, DBP and MAP) values between the four study days.

There were significant treatment (SBP *F* 8·473, DBP *F* 8·268, MAP *F* 3·830; all *P*<0·001), time (SBP *F* 3·712, DBP *F* 5·625, MAP *F* 2·827; all *P*<0·001) and treatment × time (DBP *F* 2·049, MAP *F* 1·795; both *P*<0·001) effects on BP during the 60 min after drink ingestion. BP decreased significantly following glucose (SBP *F* 3·030, *P*<0·001; DBP *F* 8·177, *P*<0·001; MAP *F* 2·131, *P*=0·005) and Fanta Orange (SBP *F* 2·136, *P*=0·005; DBP *F* 2·871, *P*<0·001; MAP *F* 2·827, *P*<0·001) ingestion, but did not change significantly following water ingestion (SBP *F* 1·111, *P*=0·341; DBP *F* 0·341, *P*=0·381; MAP *F* 1·327, *P*=0·260). SBP (*F* 2·023, *P*=0·008) and MAP (*F* 2·131, *P*=0·005), but not DBP (*F* 1·456, *P*=0·102) increased significantly following Apple & Cherry Juice ingestion. Glucose and Fanta Orange had similar effects on post-ingestion SBP, DBP and MBP (all *P*>0·05). Similarly, water and Apple & Cherry Juice ingestion also had similar effects on postprandial BP measurements (all *P*>0·05). Fanta Orange
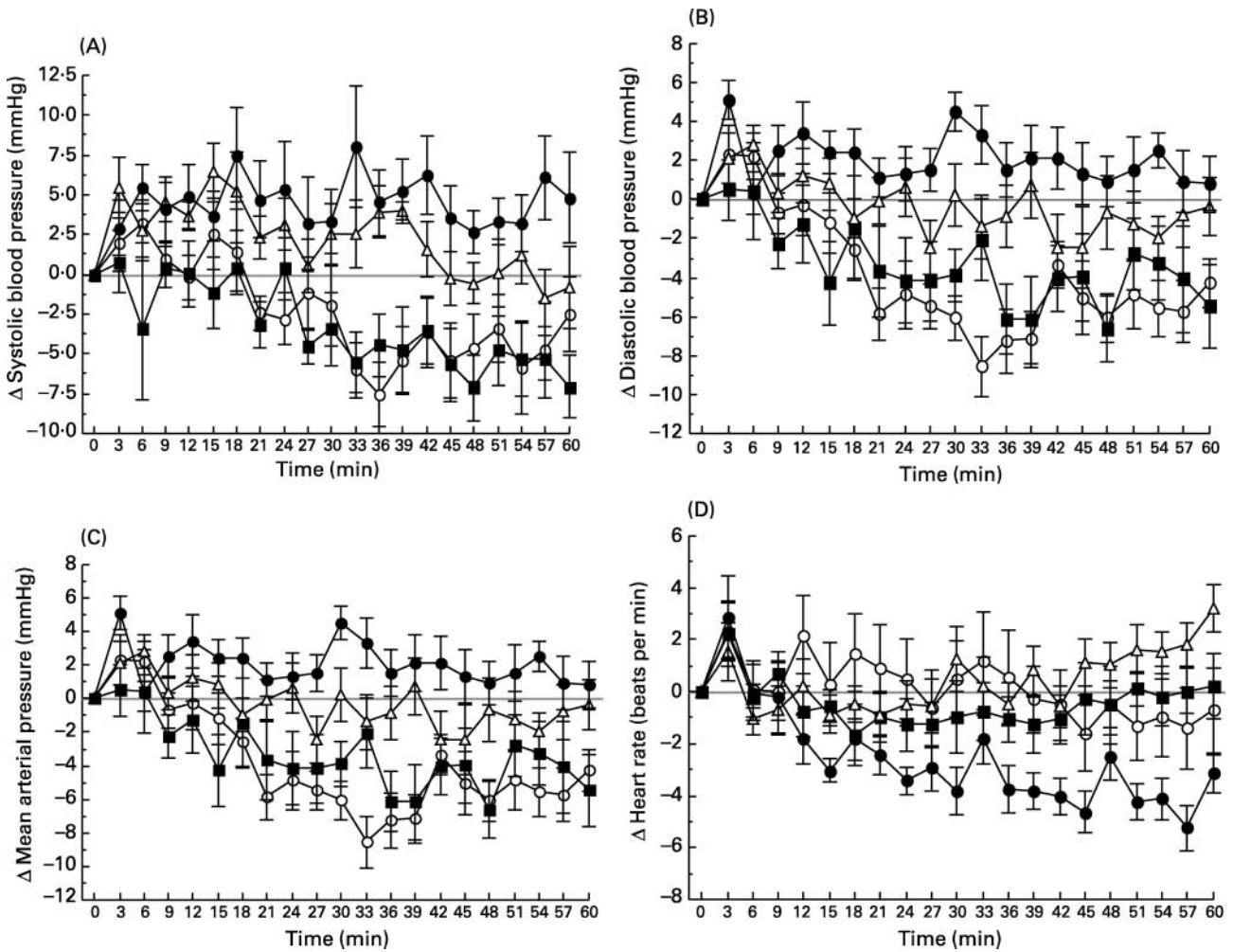
Fig. 2. The mean blood pressure and heart rate change from baseline (mmHg) following the ingestion of the four different test drinks in ten healthy older people. (A), systolic blood pressure; (B), diastolic blood presure; (C), mean arterial pressure; (D), heart rate. ○, Glucose; ■, Fanta Orange; Δ, Apple & Cherry Juice; ●, water. For details of subjects, drinks and procedures, see p. 336. Values are means with their standard errors shown by vertical bars.

ingestion was associated with a greater fall in BP than Apple & Cherry Juice ingestion (SBP and DBP $P < 0.001$, MAP $P = 0.082$) in the first 60 min.

Glycaemic effect and blood pressure change

There was no significant correlation between the glycaemic responses to the carbohydrate drinks and the change in

SBP (r -0.123, $P = 0.509$), DBP (r -0.051, $P = 0.784$) and MAP (r -0.069, $P = 0.712$) from baseline to time t (mean 30–60 min).

Heart rate

The HR responses to the drinks are shown in Fig. 2(D). There was no significant difference in the baseline HR
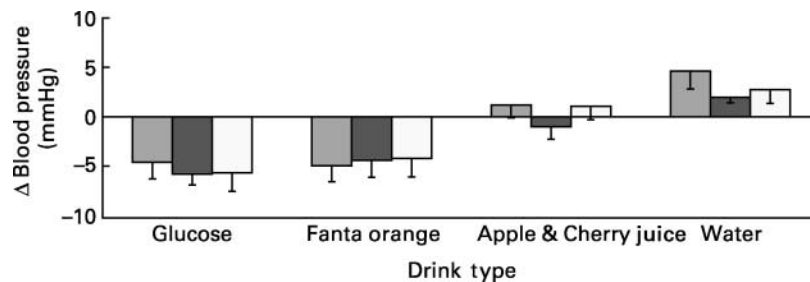

Fig. 3. Change in blood pressure measures from baseline at time t (mean measures for t 30–60) after the consumption of the four study drinks. ▨, Systolic blood pressure; ■, diastolic blood pressure; □, mean arterial pressure. For details of subjects, drinks and procedures, see p. 336. Values are means with their standard errors shown by vertical bars.

values between the four study days. Significant treatment (F 3·476, $P=0·030$), time (F 3·078, $P<0·001$) and treatment × time (F 2·891, $P<0·001$) effects were seen. The HR did not change significantly from baseline in the 60 min after glucose (F 1·558, $P=0·067$) and Fanta Orange (F 1·406, $P=0·121$), increased following Apple & Cherry Juice (F 2·919, $P<0·001$), and decreased following water ingestion (F 6·144, $P<0·001$). *Post hoc* analysis showed that glucose, Fanta Orange and Apple & Cherry Juice had similar effects on HR ($P>0·05$), which were all significantly different from the bradycardic effect seen following water ingestion ($P<0·001$).

Discussion

The major finding of the present study was the lack of a significant relationship between the glycaemic effects of the three 50 g carbohydrate drinks and the BP changes after their ingestion. No significant correlation between the fall in BP measurements and the glycaemic response after the ingestion of the carbohydrate drinks was found. It is not possible, therefore, to predict with any accuracy the BP response to a particular carbohydrate drink from its glycaemic effect. This was exemplified by the different BP responses to Apple & Cherry Juice and Fanta Orange. Their glycaemic effects were very similar, but their effects on BP were clearly different, with a slight rise after Apple & Cherry Juice, fall after Fanta Orange, and significant difference between these responses.

The fall in BP following the ingestion of carbohydrate drinks is related in part to the gastrointestinal response to their ingestion and not the ensuing hyperglycaemia, as indicated by previous findings that intravenous glucose administration does not cause a fall in BP whilst oral glucose consumption resulting in a similar glycaemic response, does (Jansen *et al.* 1987). A reduction of luminal glucose exposure is likely to attenuate the fall in BP, perhaps by preventing or delaying the release of vasoactive gut peptides; this is supported by a recent study by our group in which the addition of guar (naturally occurring, gel-forming carbohydrate of vegetable origin) to an intraduodenal glucose infusion attenuated the fall in BP and rises in blood glucose, plasma insulin, glucagon-like peptide-1 and glucose-dependant insulinotropic polypeptide induced by intra-duodenal glucose (O'Donovan *et al.* 2004).

Our present results suggest that the change in BP following the ingestion of these carbohydrate drinks is determined by factors other than their glycaemic effects. Although the Fanta Orange was allowed to de-carbonate in air for 20 min before consumption, it was still carbonated compared with Apple & Cherry Juice. Factors that decelerate gastric emptying of carbohydrate solutions act to decrease their glycaemic effect and attenuate the drop in BP (Jones *et al.* 1998, 2001). We did not measure the rate of gastric emptying in the present study, but several studies have examined the effect of carbonation of drinks on the rate of gastric emptying, and found either a delay (Ploutz-Snyder *et al.* 1999) or no effect (Ryan *et al.* 1991; Pouderoux *et al.* 1997). The lower BP readings after Fanta Orange than after Apple & Cherry Juice are therefore unlikely to be due to any effects of drink carbonation on gastric emptying. It remains possible that another, unknown effect of carbonation, may be involved.

We think a more likely cause is the differing types of saccharides contained in these drinks. The fall in BP from baseline following the ingestion of glucose in the present study is consistent with the results of previous studies (Jones *et al.* 2001; O'Donovan *et al.* 2002). When the effects on BP of a fructose drink (75 g fructose in 300 ml) were compared with those of an equi-energetic glucose drink (75 g glucose in 300 ml) in older people, there was no significant change in BP following fructose ingestion, while BP fell significantly following glucose (Jansen *et al.* 1987). Analysis of the carbohydrate in the drinks in the present study indicated that 50 % in the Apple & Cherry Juice was fructose and approximately 30 % was glucose (25·0 *v.* 15·0 g), with a fructose:glucose ratio 1·7:1·0, whereas fructose and glucose both comprised 45 % of carbohydrate in Fanta Orange (22·5 g each), with a fructose:glucose ratio 1·0:1·0. Even if allowance is made for complete postprandial breakdown of the sucrose in these drinks to equal parts fructose and glucose, the fructose:glucose ratio decreases only slightly to 1·5:1·0 (30·0 *v.* 20·0 g) for the Apple & Cherry Juice and is unchanged at 1·0:1·0 for Fanta Orange (25·0 g each). As glucose lowers BP but fructose does not, the differing effects on BP of these drinks may be due to the greater amounts of fructose than glucose, both absolutely and relatively, in the Apple & Cherry Juice.

In the present study, we chose the drinks based on their published GI, as the GI is a surrogate marker for the glycaemic effects of food. However, we found that Fanta Orange and Apple & Cherry Juice had similar glycaemic effects despite having differing published GI. The direct comparison of the published GI values with our findings is not possible as we had not followed strict GI estimation methodology in that: (1) we did not measure capillary blood glucose values; (2) each drink was not tested three times to reduce intra-subject and day-to-day variation; (3) most published GI studies have studied the glycaemic response of food in younger people, as the GI may vary with age; (4) the drinks were consumed in 3 min as opposed to 15 min used with GI testing (Wolever *et al.* 1988, 2003; Miller *et al.* 1995; Foster-Powell *et al.* 2002).

In conclusion, the decrease in BP seen after the consumption of 50 g carbohydrate drinks of equal volume is not closely related to, or predictable from, the glycaemic effects of the drink. It is more likely to be determined by the nature of the sugars in the drink. As equi-energetic drinks containing differing carbohydrates have varying effects on postprandial BP, manipulation of the carbohydrates in a meal may provide a means of reducing PPH. This requires more investigation and confirmation in a population with PPH.

Acknowledgements

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