Effects of Sweetness and Energy in Drinks on Food Intake Following Exercise

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KING, N. A., K. APPLETON, J. ROGERS AND J. E. BLUNDELL. Effects of sweetness and energy in drinks on food intake following exercise. PHYSIOLOGICAL BEHAVIOR 66(2) 375–379, 1999.—Exercise is known to cause physiological changes that could affect the impact of nutrients on appetite control. This study was designed to assess the effect of drinks containing either sucrose or high-intensity sweeteners on food intake following exercise. Using a repeated-measures design, three drink conditions were employed: plain water (W), a low-energy drink sweetened with artificial sweeteners aspartame and ace-sulfame-K (L), and a high-energy, sucrose-sweetened drink (H). Following a period of challenging exercise (70% VO₂ max for 50 min), subjects consumed freely from a particular drink before being offered a test meal at which energy and nutrient intakes were measured. The degree of pleasantness (palatability) of the drinks was also measured before and after exercise. At the test meal, energy intake following the artificially sweetened (L) drink was significantly greater than after water and the sucrose (H) drinks (p < 0.05). Compared with the artificially sweetened (L) drink, the high-energy (H) drink suppressed intake by approximately the energy contained in the drink itself. However, there was no difference between the water (W) and the sucrose (H) drink on test meal energy intake. When the net effects were compared (i.e., drink + test meal energy intake), total energy intake was significantly lower after the water (W) drink compared with the two sweet (L and H) drinks. The exercise period brought about changes in the perceived pleasantness of the water, but had no effect on either of the sweet drinks. The remarkably precise energy compensation demonstrated after the higher energy sucrose drink suggests that exercise may prime the system to respond sensitively to nutritional manipulations. The results may also have implications for the effect on short-term appetite control of different types of drinks used to quench thirst during and after exercise. © 1999 Elsevier Science Inc.

It has been argued that sweetness and energy exert separate effects on appetite control, and that these two aspects of foods or drinks can be experimentally uncoupled (6). Experiments have produced varying outcomes, and reviews have come to very different conclusions regarding the effects of high intensity sweeteners on appetite control (2,7,9). At the present time there is no agreement on whether sweetness (mediated by artificial sweeteners) stimulates or inhibits food consumption. A number of methodological problems have played a role in the failure of experiments to produce a consensus of opinion. This has been discussed in detail elsewhere (2). Artificial sweeteners (such as saccharin, acesulfame-K, and aspartame) and sugars (sucrose, glucose, fructose, etc.) can be used to manipulate the sensory and nutritional properties of foods or beverages. The separate effects of sweetness and energy can then be evaluated using the additive and substitutive procedures (7). Artificial sweeteners can be added to nonsweet materials to provide sweetness without alterations of the energy value. These two materials can be used to compare the effects of sweetness on appetite with energy value held constant. This has been called the additive procedure (7). Artificial sweeteners can also be used to replace a carbohydrate sweetener so as to maintain an equivalent level of sweetness while reducing energy value. This has been called the substitutive procedure (7). In the design of experiments, the additive procedure is required to assess the effects of sweetness (holding energy constant), while the substitutive procedure is required to demonstrate caloric adjustments (holding sweetness constant). It is worth noting that only the additive procedure provides comparisons that can throw light on the capacity of artificial sweeteners to stimulate appetite. In this study we have used the additive and substitutive proce-

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dures to investigate the effects of sweetness and energy in drinks following exercise.

METHODS

Subjects

Sixteen healthy male volunteers were recruited from the student/staff population of Leeds University. Table 1 shows the subjects' characteristics. Before taking part in this study subjects completed several questionnaires to ensure that they were unrestrained eaters, of sound mental and physical health, and that they participated in at least 3 h of physical activity per week. Each subject had his VO$_2$ max assessed using a standard incremental exercise test using a treadmill. The test required the subject to run at a constant speed (6 mph) while the gradient of the treadmill increased every 2 mins until volitional exhaustion. At this stage VO$_2$ max was reached using the following criteria: (a) a final respiratory quotient (RQ) of $>1.15$, and (b) oxygen consumption increased by $<2.0$ mL/kg with an increase in intensity.

Experimental Design

This was a repeated-measures design; therefore, subjects acted as their own control. There were three treatment conditions. The three treatment conditions varied according to the type of postexercise drink available (Fig. 1). The three treatment conditions were: 1) exercise—bottled mineral water (W) (nonsweet, no energy); 2) exercise—low-energy, artificially sweetened fruit drink (L) [Smithkline Beecham (UK) Ribena—blackcurrant] (mixture of aspartame and Acesulfame-K) (sweet, low energy); 3) exercise—high-energy, sucrose-sweetened fruit drink (H) [Smithkline Beecham (UK) Ribena—blackcurrant] (sweet, high energy—1.68 kJ/g).

Exercise Sessions

The exercise was long-duration, high-intensity (approximately 45 min at 70% VO$_2$ max) treadmill running. Each exercise session was designed to be equal both in intensity and duration. These exercise sessions induce a significant increase in energy expenditure and have been used in previous studies (4,5).

Procedure

Subjects arrived at the Human Appetite Research Unit (HARU) in the morning to be given a standard breakfast of their own choice. They remained in the laboratory for the remainder of the experiment until 1400 h. At approximately 1100 h subjects ran on a treadmill for approximately 50 min at 70% VO$_2$ max. At the end of the exercise session each subject was provided with an opaque bottle containing either 750 mL of manufacturer’s still water, a sweet, low-energy, or a sweet, high-energy drink to consume.

Postexercise Drinks

Each of the sweet drinks (L and H) were designed to be equal in palatability and sweetness, but different in energy content. A pilot study was carried out prior to the experiment to ensure that these criteria were fulfilled. In the present study subjects were instructed that they could drink as little or as much of the available drink as they wished. Therefore, subjects were allowed to drink to satisfy their individual requirements and were not forced to consume all the drink. They were also instructed that, after showering, an ad libitum test meal was available at 1215 h and not before this time.

Test Meal

The test meal consisted of three nonsweet and four sweet foods. All the foods were high carbohydrate/low fat (FQ $<0.85$), and were designed to have a carbohydrate content of $>50\%$ by energy. The composition (% energy from each macronutrient) of the test meal was 15% protein; 18% fat, 67% carbohydrate. Subjects were allowed to eat any time after 1215 h. Whenever they felt the need to eat, subjects collected the food from a refrigerator and then ate alone in an eating cubicle in the HARU.

Visual Analogue Scales

Visual analogue scales (150 mm) were used to monitor subjective feelings of hunger periodically throughout the treatment day. This was immediately before and after the breakfast and test meal as well as immediately before, during and every 5 min after the exercise sessions. These word-anchored ratings have been described in a previous study (4).

Pre- and Postexercise Sample Test

A 20-mL sample of the drink was given to the subjects to drink immediately before and immediately after the exercise sessions. The sample solutions were taken from the same solution as the postexercise drink from that particular treatment, and were, therefore, identical in taste, sweetness, and caloric content. Immediately after tasting the solution sub-

TABLE 1
SUBJECT CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (kg/m$^2$)</th>
<th>VO$_2$ max (mL/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (±SD)</td>
<td>21.3 (12.4)</td>
<td>177.8 (5.7)</td>
<td>72.9 (11.2)</td>
<td>22.8 (3.0)</td>
<td>51.7 (7.1)</td>
</tr>
</tbody>
</table>

FIG. 1. A schematic diagram summarising the energy and sweetness value of the postexercise drinks used in the three conditions.
jects rated the sample drink on the following characteristics: pleasantness, palatability, sweetness, and their desire to drink it, using 100-mm visual analogue scales that were labelled at the anchors, depending on the question. For example: How sweet did you find this drink? (Extremely sweet) and (Not at all sweet). These ratings were also filled in by the subjects immediately after consuming the postexercise drink. Therefore, for each treatment there were three time periods of rating; immediately before and after exercise (pre- and postexercise), and immediately after consuming the postexercise drink (postdrink).

**Statistical Analysis**

A two-way analysis of variance ANOVA (with time and condition as the repeated measures) was used to analyse the VAS and the pre-/postexercise sample drinks data. A one-way repeated measures ANOVA was used to analyse the test meal and the postexercise drinks data. Both ANOVAs were conducted using the statistical package SAS (Statistical Analysis Systems, Inc., Box 8000, North Carolina). Student’s t-tests were used to make comparisons between pairs of treatments.

**RESULTS**

**Exercise Session**

The exercise sessions were designed to be identical in intensity and duration. A one-way ANOVA confirmed that there was no significant difference in the intensity, $F(2, 30) = 0.98$, NS, or energy expenditure, $F(2, 30) = 0.65$, NS, between the three exercise sessions for each condition.

**Subjective Ratings**

There was no significant difference in subjective feelings of hunger between the three conditions, $F(2, 30) = 0.04$, NS. As expected, there was a significant effect of time on feelings of hunger, $F(9, 135) = 30.92$, $p < 0.001$. There was no significant exercise by time interaction, $F(18, 270) = 0.85$, NS. Figure 2 shows the profiles of hunger during all three conditions. Although there was not a strong suppression of hunger during and after exercise, in all conditions the rise in hunger was curbed. The type of postexercise drink did not significantly affect feelings of hunger during the immediate postexercise period.

**Time to Onset of Eating**

There was no significant difference in the times to onset of eating between the three treatments, $F(2, 30) = 0.03$, NS. Subjects waited approximately 10 min before choosing to eat the test meal in all three conditions.

**Postexercise Drinks**

There was a significant difference in the amount of drink consumed between the three conditions, $F(2, 30) = 5.57$, $p < 0.05$. Subjects drank significantly more of the artificially sweetened drink (L) compared with the water (W) ($t = 3.19$, $p < 0.01$), but there was no significant difference between W and H, $t(15) = 1.88$, NS, or L and H, $t(15) = 1.17$, NS. However, there was no significant relationship between the volume of drink consumed and test meal food intake ($r = -0.05$, NS) in all three conditions. As expected, there was a significant difference in the resulting energy intake of the drinks consumed, $F(2, 30) = 146.83$, $p < 0.001$, between the three treatments, because in the W treatment water (no energy) was consumed and in the L condition the drink was designed to be extremely low energy.

**Test Meal**

A one-way ANOVA revealed that there was a significant effect of drink condition on the weight of food consumed, $F(2, 30) = 4.54$, $p < 0.05$. Post hoc t-tests indicated that subjects ate significantly more food during the test meal in the L condition than in the W condition, $t(15) = 2.58$, $p < 0.05$, and the H condition, $t(15) = 2.32$, $p < 0.05$. There was also a significant effect of condition on test meal energy intake (MJ), $F(2, 30) = 4.61$, $p < 0.05$. Energy intake was significantly higher in L than in the W, $t(15) = 2.61$, $p < 0.05$, and the H conditions, $t(15) = 2.30$, $p < 0.05$. However, there was no significant difference between the H and the W conditions, $t(15) = 0.49$, NS. Thirteen (out of the 16) subjects increased their test meal intake in the L condition compared with the W condition. Therefore, the low-energy, artificially sweetened drink stimulated both the weight of food consumed and energy intake. However, the high-energy, sweet drink (H) appeared to “block” energy intake during the test meal by approximately the same amount that was consumed from the postexercise drink itself (see Table 2). That is, the total energy intake (drink and test meal combined) was significantly affected by condition, $F(2, 30) = 5.38$, $p < 0.01$, but combined intakes did not differ significantly between the L and H conditions, $t(15) = 0.39$, NS. However, combined energy intake in the L condition, $t(15) = 2.78$, $p < 0.05$, and in the H condition, $t(15) = 3.53$, $p < 0.01$, was significantly higher than in the W condition. There were no significant effects of drink condition on macronutrient intake during the test meal, $F(2, 30) = 0.78$, NS.

**Pre- and Postexercise Sample Drinks**

Small samples (20 mL) of the postexercise drink were given to subjects to drink immediately before and immediately after exercise to assess the perceived pleasantness and sweetness of the drinks before and after exercise, and after consuming a large amount of the drink itself. Figure 3a and b show the profiles of ratings over the three time periods (pre-, postexercise, and immediately after consuming the postexercise drink). Analysis of the perceived pleasantness of the three drinks was significantly different, $F(2, 30) = 15.29$, $p <$
0.001, with water being rated as the least pleasant. A two-way ANOVA revealed that there was a significant effect of time on perceived pleasantness of the drinks, $F(2, 30) = 6.30$, $p < 0.01$, but not on perceived sweetness, $F(2, 30) = 0.26$, NS). As expected, there was a significant difference between perceived sweetness of the three drinks, $F(2, 30) = 73.56$, $p < 0.001$.

**DISCUSSION**

In this study a test of the additive procedure involved a comparison between the water and the low-energy, artificially sweetened drink. The low-energy, artificially sweetened drink significantly raised test meal energy intake compared with water indicating a stimulatory effect of sweetness on appetite. This short-term action has been demonstrated on a number of previous occasions under carefully controlled conditions using fluids or yoghurt-type foods as the carrier for the sweetening agent (6–8). Compared with the artificially sweetened drink, the high-energy, sucrose-sweetened drink suppressed test meal intake. In fact, subjects appeared to precisely compensate for the energy content of the postexercise drink, by reducing energy intake in the test meal by approximately 1 MJ. Therefore, the high-energy sweet drink appeared to have attenuated energy intake during the test meal. However, when the high-energy sweet drink was compared with the water drink, there was no difference in test meal energy intake. Therefore, it is possible that the effect produced with the high-energy sweet drink is due to the high-energy value (rather than an effect of sweetness per se), because energy value is the only difference between the L and H drinks. The energy value of the high-energy sweet drink also prevented any significant reduction in overall energy intake (drink energy plus meal energy). The comparison of effects of the low-energy, artificially sweetened drink with the high-energy sweet drink conforms to the substitutive experimental procedures and, in this study, has indicated the power of carbohydrate energy to suppress later food consumption over a short (and limited) time period. Interestingly, although this effect has been observed in previous studies (1), the precision of the compensation was greater in this experiment. We suggest that this is due to the sensitising effects of exercise on physiological responses. The practical implication is that there is no real difference between consuming an artificially or naturally sweetened drink after exercise because the two sweet (L and H) drinks exerted the same net effect (drink plus test meal) on energy intake. However, of most practical importance is that drinking water after exercise had the net effect of lowering energy intake because the combined energy intake (drink plus test meal) after the water drink was significantly less compared with the two sweet drinks.

One incidental finding of this study involved changes in subjective ratings. Subjects were required to evaluate the sensory characteristics of the drinks before and after exercise. Exercise significantly raised the perceived pleasantness of water, but there was no effect on the pleasantness of the two sweet drinks. This was almost certainly due to a ceiling effect;
the initial ratings for the sweet drinks being so high initially as to preclude any further increase. It is also possible that the sucrose concentrations of the drinks were too high to be sensitive to changes in perception of palatability, because exercise has previously been shown to induce changes in taste perceptions at low sucrose concentrations (10). The effect of exercise (energy and fluid depletion) on the hedonic rating of water is reminiscent of the phenomenon of alliesthesia (3). Here, the perceived pleasantness of water is linked to the biological "usefulness" of water in rehydrating the system after exercise. In summary, these results have drawn attention to the fact that postexercise drinks exert an influence on the short-term control of appetite. The data have shown that sweetness stimulated food intake during a postexercise test meal, and carbohydrate suppressed intake. Therefore, carbohydrate (in the form of sucrose) was monitored precisely during the postexercise period and exerted a potent effect on appetite (food intake). Of course, because the net effect on energy intake (drink energy plus test-meal energy) was the same for both sweet drinks, it can be deduced that, under these circumstances, they have equivalent effects on weight control. In the same token, the water drink had a net effect of lowering energy intake. The use of this experimental design—exercise plus a sensory/nutrient manipulation—has made a contribution to the understanding the effects of taste and energy on short-term appetite control, and has provided some suggestions for future research on the effects of exercise and fluids on weight control.

ACKNOWLEDGEMENTS

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