The Effects of Beverage Carbonation on Sensory Responses and Voluntary Fluid Intake Following Exercise

Dennis H. Passe, Mary Horn, and Robert Murray

The effects of carbonated beverages on sensory acceptability and voluntary fluid intake after exercise were examined. The level of carbonation in a 6% carbohydrate (CHO) electrolyte drink was systematically varied (0, 1.1, 2.3, and 3.0 volumes of \( \text{CO}_2 \)), and its impact was assessed in 52 adults following 30 min of exercise. The perception of carbonation intensity closely tracked the differences in physical carbonation levels presented, with all perceived intensities significantly different from each other \((p < .01)\). Overall sensory acceptability, perceived thirst quenching, and perceived sweetness were significantly lower for 2.3-vol \( \text{CO}_2 \) and 3.0-vol \( \text{CO}_2 \) than for 0-vol \( \text{CO}_2 \) and 1.1-vol \( \text{CO}_2 \) \((p < .01)\). Perceived throat burn was significantly higher for 2.3-vol \( \text{CO}_2 \) and 3.0-vol \( \text{CO}_2 \), than for 0-vol \( \text{CO}_2 \) and 1.1-vol \( \text{CO}_2 \) \((p < .01)\). Total fluid intake for 0-vol \( \text{CO}_2 \) and 1.1-vol \( \text{CO}_2 \) was significantly higher than for 2.3-vol \( \text{CO}_2 \) \((p < .05)\), which was significantly higher than for 3.0-vol \( \text{CO}_2 \) \((p < .05)\). It was concluded that levels of carbonation equal to or in excess of 2.3-vol \( \text{CO}_2 \) negatively impact drink acceptability and voluntary fluid intake.

Key Words: electrolyte, athlete, sensory

Athletes must often consume large amounts of fluid during competition and training to replace the sweat lost during these activities. Research has shown that flavored beverages are preferred and consumed more avidly than plain water during and following physical activity \((6, 11, 12, 20, 21, 23)\). Rolls \((20)\) concluded that the presence of flavor is a major determinant of the amount of fluid ingested. Sweetening a drink will also enhance its palatability and intake \((21)\). The American College of Sports Medicine \((2)\) has recognized the role of palatability in an oral rehydration fluid by concluding that “enhancing palatability of an ingested fluid is one way of improving the match between fluid intake and sweat output” \((p. iii)\). Gisolfi and Duchman \((9)\), in preparing guidelines for optimal replacement beverages, stressed the importance of palatability to encourage drinking.

While the presence of flavor and sweetness may help adults overcome their tendency to underconsume fluids during physical activity, other sensory

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characteristics of fluids may have deleterious effects on drink acceptability and subsequent intake. For example, unpalatable flavors have substantial negative effects on drink acceptability and fluid intake following exercise (11, 12). Sohar et al. (23) reported that young men (18–21 years) marching in the desert preferred noncarbonated, sweetened, citrus-flavored beverages from among an array that included water, soda water, cola, milk, and beer. The subjects dramatically underconsumed water when it was warm (41°C). Carbonation was described as being negative, and the subjects were observed to shake the bottles to release the gas when required to consume carbonated drinks. Subjects reported that carbonation imparted a feeling of fullness in the stomach that they perceived as negative (23). In studies in our laboratory in which various carbonated soft drinks have been consumed following exercise, similar comments have been made (unpublished observations), especially under conditions in which the subjects attempted to consume the drinks quickly and in the larger volumes often required during and following physical activity.

Levels of carbonation typically found in soft drinks range from 1 to 2 volumes of CO₂ for low levels, 2 to 3 volumes of CO₂ for medium levels, and beyond 3 volumes for higher levels of carbonation (13). The purpose of this investigation was to assess the impact of a range of beverage carbonation levels on drink acceptability and fluid intake in an exercise occasion. A 6% carbohydrate (CHO) electrolyte control drink was compared to the same formulation carbonated to 1.1, 2.3, or 3.0 volumes of CO₂. The control and carbonated variables contained sodium benzoate, a preservative commonly used in carbonated drinks and shown in previous unpublished research in our laboratory to have a negative impact on palatability when present at higher levels. A non-sodium-benzoate control was also included in this study to assess the possible impact of sodium benzoate on sensory perception and fluid intake.

Method

Subjects

Fifty-two healthy nonsmoking adults (30 males, 22 females) who engaged in 30 min of aerobic activity at 75–85% of age-predicted heart rate (HR) two to four times per week served as subjects. Subjects were required to be able to complete 30 min of aerobic activity at 75–85% of age-predicted heart rate in order to participate in the study. Mean age ± standard error was 38 ± 1.3 years. Subjects provided informed consent to participate in the study.

Procedures and Measures

Subjects exercised for 30 min at an intensity of 75–85% of their maximum age-predicted HR (1, 7). The exercise circuit consisted of aerobic and strength-training stations that included stationary bicycles, a cross-country ski simulator, rowers, a treadmill, a low-impact climber, a stair-climber, a free-weight station, an abdominal board station, and a jump-rope/chin-up station. Ambient room temperature was approximately 24°C with a relative humidity of approximately 60%. Subjects moved to another exercise station every 5 min. Each subject was given ad libitum access to a single drink immediately following exercise (no time limit) and was required to complete a sensory questionnaire. Subjects voluntarily ceased drinking
within 15 min. Drinks were assigned to subjects according to a Latin square to control for position effects. Subjects were exposed to all drink conditions, completing five exercise/drink-evaluation sessions.

All drinks were formulated to contain the same 6% CHO content (as a blend of sucrose and glucose syrup solids), electrolyte blend (3.0 mEq/L potassium, 20 mEq/L sodium), and lemon–lime flavor levels. Three drinks were carbonated (1.1, 2.3, and 3.0 volumes of CO₂) and contained 300 ppm sodium benzoate as a preservative. Two noncarbonated controls were prepared, one with 300 ppm sodium benzoate and one with no sodium benzoate. Drink characteristics and analytical results are presented in Table 1. All drinks were served in identical 10-oz bottles with hand-capped 10.3-mm closures and were labeled with a two-digit code. The beverages were cooled to approximately 6.1 °C before serving.

Drinks were evaluated for intensity of carbonation, throatburn, filling-sensation, sweetness, and thirst quenching with 100-point scales (3, 24), anchored on the left by not ___ or no ___ and anchored on the right by very ___ or strong ___. For example, the perceived intensity of sweetness was assessed using a scale anchored on the left by not sweet and anchored on the right by very sweet. Subjects were instructed to place a mark across the line at the point corresponding to their perception of sweetness intensity. Liking of carbonation, liking of sweetness, and overall acceptance were measured using a 9-point hedonic scale (4, 19). Scale categories were like extremely, like very much, like moderately, like slightly, neither like nor dislike, dislike slightly, dislike moderately, dislike very much, and dislike extremely. A 5-point just-about-right (relative-to-ideal) scale was used to assess departure from subject-defined ideal levels of carbonation, sweetness, and flavor intensity (18, 24). Scale categories were much too ___, somewhat too ___, just about right, not quite ___ enough, and not nearly ___ enough. Amount consumed (in grams) was determined by weighing individual bottles with the unconsumed portion and subtracting this value from a standard full-bottle weight.

**Statistics**

ANOVA with subject, drink, and order terms (SPSS Version 6.1.2, SPSS Inc.) were used to analyze perceived intensities of carbonation, throatburn, filling

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<th>Table 1 Drink Characteristics</th>
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<td>Brix (degrees)</td>
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*Note.* Brix is a relative measure of CHO content based on refractive index.

*No sodium benzoate.*
sensation, sweetness, perception of thirst quenching, liking of carbonation, liking of sweetness, overall acceptance, and fluid intake. Duncan Multiple Range Tests were employed to assess mean drink differences when \( F \) ratios reached \( p \leq .05 \) (26). Results of just-about-right scales for carbonation, sweetness, and flavor were analyzed as confidence intervals about differences between percentages (3, 8). Confidence intervals of 95%, which did not include 0, met the criterion of achieving significance at the .05 alpha level. For purposes of analysis, the categories of much too and somewhat too were combined, as were the categories of not quite enough and not nearly enough.

**Results**

There were no significant differences between the two control samples (one with sodium benzoate, the other without) on any sensory variable. There was, however, an effect of sodium benzoate on amount consumed. Significantly less control beverage with sodium benzoate than control without sodium benzoate was consumed (199 g vs. 223 g, respectively, \( p < .05 \)). The control with sodium benzoate was used in all subsequent comparisons with carbonated drinks (which also contained sodium benzoate).

Regarding voluntary fluid intake, significantly less of the 3.0-vol CO\(_2\) than of the other drinks was consumed (\( p < .05 \), Figure 1a). Significantly less of the 2.3-vol CO\(_2\) drink was consumed than either of the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks (\( p < .01 \)). There was not a significant difference in amount consumed between the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks. Figure 1b reveals that the overall acceptance scores for the 2.3-vol CO\(_2\) and 3.0-vol CO\(_2\) drinks were significantly lower than for the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks (\( p < .01 \)). Similarly, Figure 1c indicates that the 2.3-vol CO\(_2\) and 3.0-vol CO\(_2\) drinks were perceived to be less thirst quenching than the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks (\( p < .01 \)).

The perceived intensity of carbonation, liking of carbonation, and relative-to-ideal results for carbonation are shown in Figure 2, a–c. As the carbonation level increased, so did its perceived intensity. All mean differences in perceived intensity of carbonation were significant (\( p < .01 \)). The liking of carbonation for the two highest levels was significantly lower than for the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks (\( p < .01 \)). Subjects liked the level of carbonation best when that level was very low or zero. The percentage of subjects indicating that the 2.3-vol CO\(_2\) and 3.0-vol CO\(_2\) drinks were either somewhat too carbonated or much too carbonated significantly exceeded that for the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks. The percentage of subjects indicating that 1.1-vol CO\(_2\) was too carbonated relative to the control drink approached statistical significance (CI\(_{95\%}\) Diff 0 to 22).

Consistent with these findings were the results of the scale measuring the perception of throatburn (Figure 3a), a drink characteristic anecdotally identified by subjects as being hedonically negative. The 2.3-vol CO\(_2\) and 3.0-vol CO\(_2\) drinks were perceived as being significantly stronger in throatburn than the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks (\( p < .01 \)). The 3.0-vol CO\(_2\) drink was perceived to be significantly more filling than the 1.1-vol CO\(_2\) drink (\( p < .05 \), Figure 3b) and approached being significantly more filling than the 0-vol CO\(_2\) drink (\( p < .10 \)). The flavor intensity of the 2.3-vol CO\(_2\) and 3.0-vol CO\(_2\) drinks was perceived to be not strong enough by a greater percentage of the subjects than the 0-vol CO\(_2\) and 1.1-vol CO\(_2\) drinks (\( p \leq .05 \), Figure 3c).
Figure 1 — (a) Mean ± SEM for amount of drink consumed (grams), (b) mean ± SEM for overall beverage acceptability (9-point sensory scale), and (c) mean ± SEM for perception of thirst quenching (100-point sensory scale).

The 2.3-vol CO₂ and 3.0-vol CO₂ drinks were perceived to be less sweet than the 0-vol CO₂ and 1.1-vol CO₂ drinks (p < .01, Figure 4a). Liking of sweetness for the 2.3-vol CO₂ and 3.0-vol CO₂ drinks was also lower than for the two lower levels of CO₂ (p < .01, Figure 4b). The percentage of subjects indicating that the 2.3-vol CO₂ and the 3.0-vol CO₂ drinks were not sweet enough exceeded that for the 0-vol CO₂ and 1.1-vol CO₂ drinks (Figure 4c).

Discussion

Although a number of studies have examined the effects of carbonation during exercise (14–17, 22, 28, 29), none have taken a systematic dose–response approach
Figure 2 — (a) Mean ± SEM for perception of carbonation (100-point sensory scale), (b) mean ± SEM for liking of carbonation (9-point sensory scale), and (c) percentage of subjects indicating too much carbonation.

To the impact of carbonation on drink acceptability during or immediately following exercise. All have used relatively few subjects (N = 7–15). In the present study we included two methodological enhancements: a dose–response approach to examine several levels of carbonation immediately following exercise, and an increased number of subjects.

We observed substantial differences between the two higher levels of carbonation (2.0-vol CO₂, 2.3-vol CO₂) and the two lower levels of carbonation (0-vol CO₂, 1.1-vol CO₂) for nearly all dependent measures (amount consumed, overall acceptance, thirst quenching, perceived intensity of carbonation, liking of
carbonation, too carbonated, throatburn, and flavor strength). The magnitude of the differences in amount consumed, between the two higher levels versus the two lower levels of carbonation, exceeded 0.7 standard deviations (SD), approaching a “large” effect size in Cohen’s nomenclature (5). (For purposes of discussion, large effect sizes are defined as mean differences exceeding 0.7 SD, and medium effect sizes include mean differences from 0.4 to 0.6 SD, after Cohen [5].) Similar magnitudes of effects between the two higher levels versus the two lower levels of carbonation were also observed for the sensory variables investigated, with perceived carbonation intensity differences being quite large (in excess of 1.7 SD). Other researchers have investigated the impact of carbonation in drinks that
Figure 4—(a) Mean ± SEM for perceived sweetness (100-point sensory scale), (b) mean ± SEM for liking of sweetness (9-point sensory scale), and (c) percentage of subjects indicating that the drink was not sweet enough.

contains 6%, 8%, or 10% CHO and that were carbonated from 1.0-vol CO2 to 2.3-vol CO2 (10, 14, 22). The sample sizes in these studies have been small (N = 7 or 8) and the results have generally not been statistically significant. However, the effect sizes, in some instances, have been large, suggesting that failure to obtain significant results may be related to low power, not the true absence of an effect.

Very large and statistically significant effects for perceived carbonation have been observed in studies investigating carbonation in a 6% CHO drink (14, 22). Based on tabulated values or estimates derived from graphs, Lambert et al. (14) and Ryan et al. (22) showed effect sizes (mean differences between carbonated vs. noncarbonated control) of 1.1 and 3.9 SD, respectively, for drinks with 2.3-vol CO2 (differences significant at p ≤ .05). The effect sizes for fluid intake observed in these studies (14, 22) were also large (1.0 and 1.1 SD, respectively) and in the
same direction as the current study. The effect (greater intake of the noncarbonated drink) was significant ($p < .05$) in the study by Lambert et al. (14). Perceived sweetness and thirst quenching effect sizes were also large (1.9 and 1.0 $SD$, respectively) in the study by Ryan et al. (22) and were consistent with the direction of effects in the current study (greater perceived sweetness and greater thirst quenching for the noncarbonated drink) but were not statistically significant. Perceived sweetness was also measured by Lambert et al. (14), but the effect size was small (0.3 $SD$), nonsignificant, and in the opposite direction of that seen in the study by Ryan et al. (14) and in the current study. Perceived filling was measured in both studies (14, 22). Lambert et al. (14) recorded a medium effect size (0.5 $SD$, not statistically significant) consistent in direction with the current study. Ryan et al. (22) recorded a small effect size (0.3, not statistically significant) and in the opposite direction of that of the current study. Overall acceptance of the drink was also measured by Ryan et al. (22), who observed a large effect size (1.0 $SD$, not statistically significant) in the same direction as the current study (greater rating of overall acceptance for the noncarbonated drink).

The impact of carbonation on fluid intake and sensory responses has also been examined in drinks containing 8% CHO (10) and 10% CHO (14, 22). Lambert et al. (14) and Ryan et al. (22) reported medium effect sizes for fluid intake in 10% CHO drinks (0.4 and 0.6 $SD$, respectively, both not statistically significant). The direction of effects was similar to that of the 6% CHO drinks (greater intake of the noncarbonated drink). Hickey et al. (10) reported a small effect size (0.3 $SD$, not significant) for fluid intake. As with 6% CHO drinks, effects sizes for perceived carbonation in 8% CHO and 10% CHO drinks were large and statistically significant. Effect sizes of 0.8 $SD$ ($p \leq .05$), 3.8 $SD$ ($p \leq .05$), and 1.7 $SD$ ($p \leq .05$) (10, 14, 22) were observed (carbonated drink perceived as being more carbonated).

Most researchers have failed to find statistically significant effects of carbonation on fluid intake or gastrointestinal distress. The reason for the failure to obtain statistically significant findings in these studies may relate to the low sample sizes used. Most of the studies used 8 or fewer subjects (10, 14–17, 22, 28). Zachwieja et al. (29) used 15 subjects, a relatively small number for making sensory assessments. A simple power analysis for a comparison of two means (one-tailed test, alpha level of .05) for the middle range of effect sizes calculated from these studies (0.3 to 0.6) indicates power ranging from only 0.13 to 0.31 (5), far below the conventional level of 0.8 for much of the biological sciences. While it is probably not feasible to use more than this number of subjects due to the complicated nature of the physiological interventions in these studies, a concomitant drawback is the relative lack of statistical power for even moderate to large effects (5). Zachwieja et al. (28) cogently pointed out that a lack of statistical effect doesn’t necessarily mean that an effect does not exist, and that a physiologically meaningful effect may exist and mean the difference between winning or losing in competition.

The present results suggest that levels of carbonation in excess of 2.3-vol CO$_2$ negatively impact drink acceptability and voluntary fluid intake following exercise. The two higher levels of carbonation used in the present study fall into the medium range of carbonation (25) and are typical of many soft drinks, with some colas being carbonated to 3.5-vol CO$_2$ or higher (13). In a follow-up study with trained athletes (unpublished results), the noncarbonated control beverage was directly compared with a commercially available carbonated sports drink (1.2-
vol CO₂, 8% CHO) following 90 min of exercise. Carbonation level, CHO level, flavor profile and level, and electrolyte profile were confounded. Interestingly, the greatest discrimination among all of the sensory attributes measured (based on size of F ratio) was for perceived carbonation intensity (F = 137.592) and dislike of carbonation (F = 36.310), far exceeding that of sweetness (F = 0.028), strength of flavor aftertaste (F = 5.699), and saltiness (F = 2.917). Although significantly less of the carbonated commercial beverage was consumed (p < .001), additional research is necessary to adequately explore carbonation and the interaction of carbonation with CHO, electrolytes, and flavor intensity on drink acceptability and fluid intake following exercise, especially for longer exercise durations.

The differences in perceived carbonation in the present study and other investigations (10, 14, 22) were pronounced and consistent with those reported by Yau and McDaniel (27), who evaluated carbonation levels over a similar range in a group of sedentary subjects. They reported a "sharp increase" in perceived carbonation intensity with increased carbonation levels (27). They also reported that the exponents of the power functions for carbonation in their study were much higher than those of the basic tastes, indicating that increases in carbonation produced greater perceptual changes than those produced by concentration changes in the basic tastants. Yau and McDaniel (27) concluded that "a small CO₂ concentration change could cause a large change in carbonation perception in a carbonated beverage system" (p. 126).

The impact of sodium benzoate on fluid intake remains unexplained. While there were no appreciable sensory differences between the two noncarbonated controls, one containing sodium benzoate and the other not, a significant difference in liquid intake was observed. It is possible that any sensory effects caused by this level of preservative were subtle and therefore not registered in the mix of sensory questions asked in this study. It is also apparent that the difference in fluid intake between the sodium benzoate- and the non-sodium-benzoate-containing controls was relatively small (24 g). In the context of this study, that amount may not be of physiological importance. A longer protocol would be required to establish the physiological relevance of this preservative on voluntary fluid intake during exercise.

In physiological investigations in which the number of subjects is necessarily small, the likelihood of achieving statistically significant results is diminished. While other strategies such as repeated-measures designs and refining experimental control to enhance effect size are critical, there continues to be the risk of "throwing the baby out with the bathwater" when failing to reach statistical significance. Useful clues and insight into the potential effects of independent variables may be discarded if we prematurely dismiss an effect, based upon negative findings from hypothesis testing. An alternative approach that can usefully augment hypothesis testing is to examine effect sizes and express findings in terms of confidence intervals (4, 8). The result of this approach in the current context is to provide the basis for estimating the effects of carbonation on a range of dependent variables, in studies with relatively low power, and relating the results to research of greater statistical power. The results of the current study generally support the direction and effect sizes found in other investigations of carbonated drinks consumed during an exercise occasion. Carbonated beverages at levels equal to or beyond 2.3 vol CO₂, consumed following exercise, negatively impact drink acceptability and voluntary fluid intake. Therefore, they are not an optimal fluid replacement choice following physical activity, when larger volumes of fluid are ingested quickly.
References


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