ABSTRACT

This study investigated the impact of alcohol mixed with artificially sweetened or carbohydrate containing beverages on breath alcohol concentrations (BrAC) under various levels of hydration status. Two groups of males participated in 3 experimental trials where alcohol was consumed under three different levels of hydration status. One group received alcohol mixed with an artificially sweetened beverage and the other group received alcohol mixed with a CHO-containing mixer in each trial. Significantly higher peak BrACs were observed when alcohol was consumed with an artificially sweetened beverage compared to a CHO-containing beverage under all levels of hydration status. Subjective ratings of intoxication and impairment were not different between the two groups under any of the hydration conditions.

Mixing alcohol with an artificially sweetened drink results in higher BrACs, but no detectable differences in feelings of intoxication. These findings may have legal consequences for individuals who consume alcohol without co-ingestion of CHO and intend to operate a motor vehicle.

Keywords: Alcohol, Artificially-Sweetened Beverages, Diet Drinks, Breath Alcohol Concentrations, Hydration, Intoxication.
INTRODUCTION

Alcohol concentrations attained in the body after drinking are subject to a combination of factors that influence the absorption, distribution and metabolism of alcohol (Eckardt et al., 1998; Lee, Yoon, Baek, & Kwon, 2013; Pohorecky & Brick, 1988). Alcohol dose is the most significant factor affecting an individual's breath alcohol concentration (BrAC), however several studies have confirmed the influence of other factors such as the presence of food in the stomach and/or meal composition on reducing alcohol concentrations (Finnigan, Hammersley, & Millar, 1998; Jones & Jönsson, 1994; Jones, Jönsson, & Kechagias, 1997; Lin, Weidler, Garg, & Wagner, 1976; Pikaar, Wedel, & Hermus, 1988; Schmidt & Oehmichen, 1985; Sedman, Wilkinson, Sakmar, Weidler, & Wagner, 1976; Shultz, Weiner, & Westcott, 1980; Welling, Lyons, Elliott, & Amidon, 1977).

The consumption of food is thought to slow gastric emptying rates, delaying entry of alcohol into the small intestine, where most alcohol absorption occurs. A reduction in gastric emptying rate allows more time for alcohol to remain in the stomach, where absorption into the systemic circulation is less rapid. Enzyme activity in the stomach amplifies first-pass metabolism (Oneta et al., 1998), increasing clearance of alcohol from the body and effectively resulting in lower and delayed times to reach peak alcohol concentrations (Hahn, Norberg, Gabrielsson, Danielsson, & Jones, 1994; Horowitz et al., 1989; Pohorecky & Brick, 1988).

Recent evidence also suggests that carbohydrate (CHO) alone when mixed with alcohol can influence BrACs (Marczinski & Stamates, 2013; Matthews, Overstreet, Rezvani, Devaud, & Morrow, 2001; Rossheim & Thombs, 2011; Wu et al., 2006), with higher levels reported after consumption of alcohol with a 'diet' or artificially sweetened mixer compared to 'regular' or sugar sweetened mixer. Previous studies have used regular alcohol beverages containing 35g CHO (Marczinski & Stamates, 2013) and 65g CHO (Wu et al., 2006) to compare against alcohol drinks with artificially-sweetened mixers. Increases in BrAC with the diet beverages were in the order of 18% and 56% for these studies respectively. Thus, the higher dose of CHO provided by
Wu et al. (2006) may have resulted in a greater blunting of BrAC response. A lower dose of CHO (<35g) than that provided by Marczinski & Stamates (2013) may then be expected to have a lesser effect on reducing BrAC.

Artificially sweetened beverages have become increasingly prevalent in the marketplace (Tuorila, Pangborn, & Schutz, 1990), and they may be combined with alcohol in low to moderate doses by individuals wishing to avoid excess sugar or caloric intake. Recent research has also shown a positive correlation between diet soft drink consumption and past 30-day alcohol use among United States Secondary School students (Terry-McElrath, O'Malley, & Johnston, 2014). Given societal concerns regarding the prevalence of overweight and obesity, the consumption of alcohol mixed with a diet or low CHO beverage has become increasingly likely (Foundation for Alcohol Research and Education, 2013; Fuhrman, 2011).

A possible explanation for the differences in BrAC response between artificially sweetened and CHO containing alcoholic drinks is that the presence of CHO in the regular drink acts in a similar mechanistic way to having food present in the stomach, reducing the rate of gastric emptying and increasing gastric first-pass metabolism (Lubman et al., 2013). Carbohydrate consumption also causes an elevation in blood glucose concentration, which has independently been shown to delay gastric emptying of solid and liquid meal components (Schvarcz et al., 1997). Iso-caloric meals differing only in CHO and protein content consumed prior to alcohol consumption have been shown to differentially affect BrACs. Meals containing high CHO (85%) and low fat (9%) appear to reduce peak BrAC compared to high protein (94%) meals that contain no CHO (Finnigan et al., 1998). Similar results have been reported by Pikaar et al. (1988), however with meals that differ in level of CHO combined with various levels of fat and protein. Alcohol consumed following a meal high in CHO (80%) appears to produce lower peak BrACs than a high fat meal with low CHO (26%). However, BrACs attained when alcohol is consumed after a high protein meal containing 36% CHO are lower than those observed with a high CHO meal. Whilst it is difficult to determine from these results the influence of the CHO content of a
meal itself on BrAC, it is possible that CHO content may influence BrAC in a dose response manner.

It appears that the CHO content of a beverage plays a pivotal role in manipulating BrAC responses. However, the amount of CHO required to cause this manipulation in BrAC is currently unknown. Previous studies have observed different magnitudes in the blunting of BrAC with alcohol beverages containing CHO doses of 35g and 65g, compared to artificially-sweetened alcohol drinks. The impact that consumption of a beverage with a lower dose of CHO (less than 35g) mixed with alcohol has on BrAC remains unclear. This is important as many individuals may choose to drive a motor vehicle following alcohol consumption with or without small amounts of CHO. It is also important from an education perspective as consumers and alcohol counselors need to be aware of the impact of consuming alcohol with or without CHO on alcohol pharmacokinetics and intoxication. In this study, the acute effects of alcohol mixed with either an artificially-sweetened (diet) mixer or regular mixer (containing ~18g CHO) on BrAC responses and subjective ratings of intoxication and impairment were examined.

METHOD

Study design

The data reported in this paper is part of a larger project exploring the influence of hydration and alcohol on performance of various cognitive and applied tasks. A secondary aim of the larger project was to determine the influence of CHO on levels of alcohol intoxication. Thus, the intoxication measures reported in this study reflect responses from participants undertaking different rehydration protocols.

Participants

Two groups of healthy male participants (n=16 and n=14) completed three trials involving the consumption of alcohol under various levels of hydration status (dehydrated (D), partially rehydrated (P), fully rehydrated (F)). The mean age of participants was 22.7±3.3 years in the first
group \(n=16\) and the 23.6±5.9 years in the second group \(n=14\). Trials were randomized via an incomplete Latin square design. Participant characteristics and drinking related habits for each group are shown in Table 1 (Results).

Data from three of our previous studies indicates that hydration status is not influential on breath alcohol concentrations or alcohol pharmacokinetics (Irwin, Goodwin, Leveritt, Davey, & Desbrow, 2012; Irwin, Leveritt, Shum, & Desbrow, 2013, 2014). Thus, analysis in this study was isolated to determining the influence of an alcoholic beverage with or without a small amount of CHO on BrAC responses at each of the hydration status levels. Participants were fully informed of the nature and possible risks of each experiment before giving written informed consent. Investigations were approved by the University's Human Research Ethics Committee.

**Experimental procedures**

Participants arrived at the laboratory fasted at 0700-0800 h. Baseline measures of BrAC were taken and a baseline blood glucose (BGL) measure was recorded using a finger prick sample (Accuchek Advantage II®, Roche) before participants were provided with a standardized breakfast to consume. After breakfast, an exercise-induced dehydration protocol was employed, followed by a period of recovery, and then fluid (water) consumption to induce the various levels of hydration status required in the experiments. Details of the standardized breakfast, dehydration protocol, fluid consumption levels and hydration conditions have been outlined elsewhere (Irwin et al., 2013, 2014).

After the rehydration phase (variation of hydration status), participants consumed an alcoholic beverage administered as vodka (Smirnoff® or Vodka O®, 37% v/v ethanol) made up with equal parts of non-alcoholic ginger beer cordial concentrate and ginger beer soft drink (Bundaberg Brewed Drinks Pty Ltd®), and one tenth the volume of lime cordial concentrate (Bickfords®, Australia). Complete details of the beverage have been outlined elsewhere (Irwin, Desbrow, & Leveritt, 2011). For one group of participants \(n=16\), the ginger beer and lime cordial
concentrates were artificially sweetened (aspartame) versions, whilst for the other group (n=14), these beverages were regular sugar-sweetened varieties containing ~18g of total CHO. The volume of the alcoholic beverage was individually calculated on the first trial using the updated Widmark equation (Watson, Watson, & Batt, 1981), taking into account total body water content as determined by body weight, height and age. The alcohol volume was intended to raise BrAC to ~0.05%. Precisely the same volume of alcohol was administered in all subsequent trials. Participants were asked to consume each drink at a steady pace over 10 min. A BGL measure was recorded 30 min after ingestion of the alcohol beverage.

BrACs were analyzed using a police grade Alcolizer LE Breathalyzer (Alcolizer Pty Ltd) with measurements taken 15 min and 30 min post ingestion, and a final measurement taken on completion of the trial (45-60 min post ingestion). Immediately prior to the 30 min sample, a subjective body symptoms scale (BSS) (Bond & Lader, 1974) and subjective intoxication and impairment scale (SIIS) (Fillmore, 2001; Harrison, Marczinski, & Fillmore, 2007) questionnaires were completed. Adaptive Visual Analogue Scales (AVAS) were used to assess subjective ratings, with each scale administered via a computerized modifiable software program - AVAS (Marsh-Richard, Hatzis, Mathias, Venditti, & Dougherty, 2009) on the screen of a laptop computer.

The body symptoms scale consisted of three separate analogue scales (tired, dizzy, nausea). Participants were presented with a 100mm line, the ends of which were marked with the terms ‘no symptoms’ (0mm) and ‘very strong symptoms’ (100mm). The degree of subjective intoxication and impairment were measured on separate 100mm visual-analogue scales. Participants rated intoxication by how much they “felt the effects of alcohol” between anchors of ‘not at all’ and ‘very much’. Subjective impairment was estimated based on a scale between ‘no impairment’ and ‘extreme impairment’. Two driving-related questions were also used to ascertain: (a) “How able are you to drive a car at this time?” (b) “How willing are you to drive a car at this time?” Ratings were reported between ‘not at all’ and ‘very much’. These scales have
been used in other studies of alcohol and driving and are sensitive to the effects of the drug (Fillmore, 2001; Fillmore, Blackburn, & Harrison, 2008; Harrison et al., 2007). Scores for each VAS was taken as the cursor position based on percentage of scale length.

**Statistical analysis**

All statistical procedures were performed using SPSS for Windows, Version 21.0 (SPSS Inc., Chicago, IL). Planned comparisons were performed for all dependent variables (BrAC, BGL, subjective ratings) using independent samples \( t \)-tests to compare results between beverage treatments for each of the different hydration status trials. Statistical significance was accepted at \( p<0.05 \).

**RESULTS**

*Demographic Characteristics and Self-Reported Alcohol Use*

No significant differences were noted between the two groups for any of the participant characteristics or on any of the self-reported drinking habits from the PDHQ (Table 1, all \( ps>0.30 \)).
Table 1. Participant characteristics and drinking related habits

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Diet Drink (n=16)</th>
<th>Regular Drink (n=14)</th>
<th>T (28)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>22.7±3.3</td>
<td>23.6±5.9</td>
<td>-0.55</td>
<td>0.590</td>
</tr>
<tr>
<td>Body weight (Kg)</td>
<td>77.3±9.1</td>
<td>74.3±10.5</td>
<td>0.82</td>
<td>0.418</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.7±5.7</td>
<td>177.9±6.4</td>
<td>-0.54</td>
<td>0.591</td>
</tr>
<tr>
<td>Alcohol consumption history (yrs)</td>
<td>5.2±3.7</td>
<td>5.9±5.5</td>
<td>-0.41</td>
<td>0.689</td>
</tr>
<tr>
<td>Drinking amount (std. drinks/occasion)</td>
<td>5.9±2.6</td>
<td>5.5±3.0</td>
<td>0.37</td>
<td>0.717</td>
</tr>
<tr>
<td>Drinking frequency (times/week)</td>
<td>1.8±1.6</td>
<td>1.2±1.5</td>
<td>1.00</td>
<td>0.323</td>
</tr>
</tbody>
</table>

Diet drink, artificially-sweetened alcohol beverage, Regular Drink, CHO-containing alcohol beverage. Values are mean±SD.

Nutritional content of alcohol beverages

Nutritional analysis of the beverages was performed using Foodworks© Version 6.0, 2009, (Xyris Software, Australia) dietary analysis software. A significant difference in nutritional content of the beverages was observed. The regular cordial concentrate mixers produced beverages that had significantly higher carbohydrate levels and overall energy content compared to the diet beverage (p<0.01). There was no difference in alcohol content (volume of vodka) between the two beverages (Table 2) (p>0.05).

Table 2. Nutritional content of the different alcohol drinks

<table>
<thead>
<tr>
<th></th>
<th>Diet Drink</th>
<th>Regular Drink</th>
<th>T (28)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol (ml)</td>
<td>113.1±8.7</td>
<td>112.3±9.9</td>
<td>0.26</td>
<td>0.795</td>
</tr>
<tr>
<td>CHO (g)</td>
<td>2.7±0.2</td>
<td>17.7±1.6*</td>
<td>-35.74</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Energy (KJ)</td>
<td>343.1±26.3</td>
<td>599.7±52.9*</td>
<td>-16.46</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Diet drink, artificially-sweetened alcohol beverage; Regular Drink, CHO-containing alcohol beverage. *Significant difference between drinks. Values are mean±SD.

Breath alcohol concentrations

BrACs were significantly higher when alcohol was consumed with the diet mixer compared to corresponding time points when alcohol was consumed with the regular mixer for each of the different hydration status trials (Fig. 1). Peak BrAC readings with the regular mixer were
achieved 15 min post ingestion for the D and F trials (0.047±0.006% and 0.045±0.007% respectively) and 45 min post ingestion for the P trial (0.044±0.005%). Peak BrAC readings with the diet mixer were achieved 15 min post ingestion for the P and F trials (0.074±0.017% and 0.072±0.015% respectively) and 30 min post ingestion for the D trial (0.072±0.017%). Comparisons of peak BrAC between the different beverages indicate a 53%, 68%, and 60% increase in peak BrAC with the diet mixer for the D, P, and F trials respectively.

![Graph showing BrAC responses under the three different hydration conditions with each beverage. D, dehydration trial; P, partial rehydration trial; F, full rehydration trial; Regular Drink, low CHO-containing alcohol beverage; Diet Drink, artificially-sweetened alcohol beverage. *Significant difference between beverages for all corresponding time points (p<0.01). Values are mean±SD.](image)

**Physiological measures**

Blood glucose data (Table 3) revealed that pre-trial values for the D trial were significantly higher with consumption of the regular mixer compared to the diet mixer (p<0.05) but no difference was noted in pre-trial measures for the P and F trials (p>0.05). Following consumption
of the alcohol beverage blood glucose levels were significantly higher in all trials with the regular mixer compared to the diet mixer \( p<0.05 \).

**Table 3. Blood glucose measures (mmol/L)**

<table>
<thead>
<tr>
<th></th>
<th>D</th>
<th>P</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diet Drink</td>
<td>Regular Drink</td>
<td>Diet Drink</td>
</tr>
<tr>
<td>Pre-trial</td>
<td>6.1±0.5</td>
<td>6.5±0.4*</td>
<td>6.3±0.4</td>
</tr>
<tr>
<td>Post alcohol consumption</td>
<td>5.5±0.5</td>
<td>9.9±1.3*</td>
<td>5.7±0.5</td>
</tr>
</tbody>
</table>

Diet drink, artificially-sweetened alcohol beverage; Regular Drink, CHO-containing alcohol beverage. D, dehydration trial; P, partial rehydration trial; F, full rehydration trial. *Significant difference between groups at same time measures \( p<0.05 \). Values are mean±SD.

**Body symptoms, subjective intoxication and impairment**

Table 4 shows the results from the subjective ratings scales under each of the hydration conditions for both beverage groups. No significant differences were observed on subjective ratings of tiredness, dizziness, or nausea between the different beverage groups for any of the hydration conditions \( p>0.05 \). Participants' subjective ratings of alcohol effects and level of impairment were also not different between the beverage groups for any of the hydration trials \( p>0.05 \). Likewise, there was no difference between beverage groups in any of the trials for ratings of ability to drive and willingness to drive \( p>0.05 \).

**Table 4. Subjective Ratings Scores (mm)**

<table>
<thead>
<tr>
<th>Scale (0mm ‘Not at All’ 100mm ‘Very Much’)</th>
<th>D</th>
<th>P</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diet Drink</td>
<td>Regular Drink</td>
<td>Diet Drink</td>
</tr>
<tr>
<td>Tiredness</td>
<td>42±30</td>
<td>49±24</td>
<td>32±30</td>
</tr>
<tr>
<td>Dizziness</td>
<td>28±30</td>
<td>31±30</td>
<td>25±22</td>
</tr>
<tr>
<td>Nausea</td>
<td>15±20</td>
<td>22±23</td>
<td>12±15</td>
</tr>
<tr>
<td>Alcohol Effects</td>
<td>65±19</td>
<td>70±13</td>
<td>63±19</td>
</tr>
<tr>
<td>Level of Impairment</td>
<td>58±20</td>
<td>57±16</td>
<td>50±22</td>
</tr>
<tr>
<td>Ability to Drive</td>
<td>37±26</td>
<td>46±27</td>
<td>39±26</td>
</tr>
<tr>
<td>Willingness to Drive</td>
<td>23±24</td>
<td>39±34</td>
<td>30±30</td>
</tr>
</tbody>
</table>

Diet drink, artificially-sweetened alcohol beverage, Regular Drink, CI-IO-containing alcohol beverage. D, dehydration trial; P, partial rehydration trial; F, full rehydration trial. Values are mean±SD.
DISCUSSION

This study compared the acute effects of a moderate alcohol dose when mixed with artificially-sweetened or low CHO-containing (~18g CHO) beverages. The results revealed that peak BrACs were significantly higher when alcohol was mixed with the artificially-sweetened beverage compared to the CHO-containing beverage. Overall, results from this study suggest that BrACs are higher in individuals who consume alcohol with artificially-sweetened mixers compared to the same amount of alcohol consumed with a mixer that contains CHO.

Observations from this study are consistent with recent reports indicating higher BrACs following the consumption of artificially-sweetened alcoholic drinks compared to CHO-containing alcoholic drinks (Marczinski & Stamates, 2013; Rossheim & Thombs, 2011; Wu et al., 2006). In their study, Marczinski & Stamates (2013) reported an 18% increase in peak BrAC with diet mixers. However, Wu et al. (2006) reported higher differences between the mixers, with a 56% increase in peak BrAC observed. Differences in peak BrAC between drinks in the current study were similar in magnitude (60% increase) to those observed by Wu et al. (2006) despite the much lower CHO content of the regular beverage used. The findings from the present study suggest that even small amounts of CHO are critical to induce manipulative effects on BrAC. However, all three studies only provided a single CHO dose for the sugar-containing beverage, and the type of beverage used in each study was considerably different. Ginger has previously been shown to accelerate gastric emptying rate (Wu et al., 2008). Given the proposed mechanism for the presence of CHO to influence BrAC responses via a reduction in gastric emptying rate (Horowitz et al., 1989; Kechagias, Jonsson, & Jones, 1999) it is possible that the ginger beer components of the alcoholic beverages used in the present study were influential in the overall effects on BrAC responses. Further investigation into a dose response effect of beverage CHO content on BrAC is required.

Dose considerations become particularly important when intoxication levels are close to enforceable jurisdiction laws. As in the previous studies, when the dose of alcohol provided in
the current study was consumed with a CHO-containing mixer, peak levels of intoxication were below the legal driving limit for operation of a motor vehicle in this jurisdiction (Australia, 0.050%). However, with consumption of the artificially-sweetened mixer, participants' peak BrAC levels were well above the legal driving limit. These findings may have direct consequences for individuals that plan to drive a motor vehicle following the consumption of alcoholic beverages prepared with artificially sweetened mixers. Consumers of alcohol and individuals advocating safe alcohol consumption or prevention programs should be aware of how consuming alcohol with or without small amounts of CHO can impact on intoxication levels. This may assist with informed decisions regarding alcohol consumption and beverage types in order to help reduce alcohol related harm.

Interestingly, in this study we observed no difference in subjective ratings of intoxication or impairment with the two beverages consumed. These results support the findings of Marczinski & Stamates (2013) who also noted that participants’ subjective ratings of intoxication, fatigue, impairment, and willingness to drive were not different when alcohol was consumed with regular or diet mixers. Collectively these results may indicate that individuals are unable to detect physiological response differences between alcoholic drinks mixed with artificially-sweetened or CHO-containing mixers. However, given the limited number of investigations to date, further research into the influence of alcohol mixed with artificially-sweetened drinks on subjective effects is required.

One of the limitations of the current study is that data was collected on two separate groups of participants. A combination of factors including age, weight, gender, body chemistry, pre-consumption conditions, and drinking experience leads to individual variability in response to alcohol effects. A within-subjects study design would reduce the influence of individual differences in alcohol response. However, the characteristics of each group of participants from this study were almost identical, which should minimize the influence of individual variability. Further investigation is also required to examine the influence of
artificially-sweetened mixers at various alcohol doses and the impact of different doses of CHO in mixers and the influence these have on BrAC responses. The addition of sobriety field-testing as a variable alongside subjective ratings of intoxication may also be a useful measure in future studies and could provide greater insight into individuals’ actual ability to perform fine and gross motor skills following the consumption of alcohol with various doses of CHO. Finally, the results of the present study are from two groups of male participants. Females are more likely to select artificially sweetened mixers for alcohol (Fowler et al., 2008), thus generalizability of the findings from this study may be reduced.

CONCLUSIONS

In summary, this study compared the influence of alcohol mixed with either an artificially-sweetened or a low CHO-containing mixer on BrAC responses and subjective ratings of intoxication and impairment. Results from the study indicate that artificial sweeteners can have a significant impact on increasing BrACs compared to the same amount of alcohol consumed in a beverage containing a small amount of CHO (~18g). These findings may have direct consequences for individuals that consume alcohol with artificially-sweetened mixers, to enable legal operation of a motor vehicle. In addition, these findings may also help to inform consumers, health educators and practitioners of prevention based programs how small amounts of CHO consumed with alcohol can reduce alcohol intoxication.

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