

## ORIGINAL INVESTIGATION

*Title:* Beer as a sports drink? Manipulating beer's ingredients to replace lost fluid.

***Running Title:***

***Beer and fluid restoration post exercise.***

***First and Corresponding Author:***

**B. Desbrow (1,2)**

APD, PhD

School of Public Health and Research Centre for Clinical and Community Practice  
Innovation, Griffith Health Institute

Griffith University

Gold Coast Campus

Queensland, Australia, 4222

+617 5552 9110

+617 5552 8679 (fax)

b.desbrow@griffith.edu.au

***Co-authors:***

**D. Murray(1) and M. Leveritt(3).**

1. School of Public Health, Griffith University

2. Research Centre for Clinical and Community Practice Innovation, Griffith Health  
Institute, Griffith University

3. School of Human Movement Studies, University of Queensland

***Funding Disclosure:***

*Funding from internal Griffith University support. No external funding conflict of interest to  
disclose.*

## **Abstract**

**Purpose:** To investigate the effect of manipulating the alcohol and sodium content of beer on fluid restoration following exercise.

**Method:** Seven male volunteers exercised on a cycle ergometer until  $1.96 \pm 0.25\%$  body mass (mean $\pm$ SD) was lost. Participants were then randomly allocated a different beer to consume on four separate occasions. Drinks included a low alcohol beer (2.3% ABV) [LightBeer], a low alcohol beer with  $25 \text{ mmol}\cdot\text{L}^{-1}$  of added sodium [LightBeer+25], a full strength beer (4.8% ABV) [Beer] or a full strength beer with  $25 \text{ mmol}\cdot\text{L}^{-1}$  of added sodium [Beer+25]. Volumes consumed were equivalent to 150% of body mass loss during exercise and were consumed over a 1h period. Body mass and urine samples were obtained before and hourly for 4h after beverage consumption.

**Results:** Significantly enhanced net fluid balance was achieved following the LightBeer+25 trial ( $-1.02 \pm 0.35 \text{ kg}$ ) compared to the Beer ( $-1.59 \pm 0.32 \text{ kg}$ ) and Beer+25 ( $-1.64 \pm 0.28 \text{ kg}$ ) treatments. Accumulated urine output was significantly lower in the LightBeer+25 trial ( $1477 \pm 485 \text{ mL}$ ) compared to the Beer+25 ( $2101 \pm 482 \text{ mL}$ ) and Beer ( $2175 \pm 372 \text{ mL}$ ) trials.

**Conclusion:** A low alcohol beer with added sodium offers a potential compromise between a beverage with high social acceptance and one which avoids the exacerbated fluid losses observed when consuming full strength beer.

**Key Words:** Rehydration, Fluid Balance, Exercise, Electrolytes, Diuresis

## Introduction

During exercise, sweat output often exceeds fluid intake, producing a fluid deficit or hypohydration. Before recommencing exercise, the hypohydrated athlete is encouraged to consume beverages in order to restore all fluids and electrolytes lost (Sawka et al., 2007). This is because hypohydration impairs performance in both high intensity exercise (Armstrong, Costill, & Fink, 1985), (Moquin & Mazzeo, 2001; Walsh, Noakes, Hawley, & Dennis, 1994) and endurance exercise (Ebert et al., 2007), as well as applied motor skills (Devlin, Fraser, Barras, & Hawley, 2001) and some cognitive performance measures (Tomporowski, Beasman, Ganio, & Cureton, 2007), particularly when the level of hypohydration exceeds 2% of body mass. Consequently, it is important to investigate factors, such as drink volume and electrolyte concentration, that may influence a beverage's ability to quickly restore fluid balance after exercise.

Complete rehydration following exercise can be achieved when an individual consumes a sodium-enriched ( $\sim 25\text{mmol.l}^{-1}$ ) beverage in an amount greater than the volume of sweat lost during exercise (Mitchell, Phillips, Mercer, Baylies, & Pizza, 2000; Shirreffs, Taylor, Leiper, & Maughan, 1996). There is also evidence suggesting that increasing electrolytes (in particular sodium) can improve the rehydration potential of a beverage (Maughan & Leiper, 1995; Shirreffs et al., 1996). The practical application of this evidence is that athletes are more likely to replace fluid deficits if consuming sodium containing beverages following exercise.

Beer has a long association with sport. Athletes have consumed beer as part of their post-match celebration for decades (Burke & Read, 1988; Dietze, Fitzgerald, & Jenkinson, 2008). In many countries, consuming beer is a major part of the social sporting culture at all levels of adult participation and as such offers a medium by which to potentially influence fluid restoration following exercise. Yet, despite beer commonly being consumed in large

volumes after exercise, there is little known of its capacity to replace fluid lost during exercise.

Clearly, the diuretic effect of alcohol (Eggleton, 1942; Murray, 1932) reduces beer's potential to function as an optimal rehydration solution. Interestingly however, low alcohol beer (i.e. 1% and 2% alcohol) and non-alcoholic beer have similar rehydrating potentials following exercise-induced dehydration, whereas increasing the alcohol content to 4% appears to delay recovery and increases urinary losses (Shirreffs & Maughan, 1997). In addition, when the body is hypohydrated (following exercise) the diuretic effect of 1000 mL of 4% alcohol by volume beer was less than when fully rehydrated (Hobson & Maughan, 2010). These studies suggest that the diuretic impact of alcohol is less pronounced after exercise-induced hypohydration and that the percentage of alcohol is likely to influence beer's rehydration potential.

Research on the effects of altering alcohol and sodium on the rehydration properties of beverages have examined each ingredient independently, but, clearly, it would be useful to investigate the concurrent effect of altering the sodium and alcohol contents of beer on its potential to influence fluid balance following exercise-induced fluid loss. It is hypothesized that a reduced alcohol, higher sodium beer will reduce post-exercise fluid losses compared to beers with higher concentrations of alcohol or without added sodium.

## **Methods**

### **Subjects**

Seven male healthy recreational athletes [29.7±4.3 y, 86.56±14.4 kg body mass, 184.4 ± 6.1 cm,  $\text{VO}_2$  peak 56.6±8.1 ml·kg<sup>-1</sup> body mass; values are mean±SD] volunteered to participate as subjects in the present study. Subject's average reported habitual alcohol intake in the 3 months prior to the study ranged from 2.5-150 g·week<sup>-1</sup>. All subjects were fully informed of the nature and possible risks of the study before giving their written informed

consent. The investigation was approved by the Human Research Ethics Committee of Griffith University.

### Experimental Design

Each subject visited the laboratory on at least five occasions. The first visit was preliminary testing to confirm participants' maximal exercise capacity. This was followed by the four experimental trials with the subject's diet and exercise being standardised before each trial. Experimental trials consisted of exercise-induced mass loss (target 2.0% body mass) followed by consumption of a test beverage containing either a commercial low alcohol beer (XXXX light (Lion Nathan Ltd), 2.3% ABV) [LightBeer], the same commercial low alcohol beer with 25 mmol·L<sup>-1</sup> of added sodium [LightBeer+25], a standard commercial beer (XXXX bitter (Lion Nathan Ltd), 4.8% ABV) [Beer] or the standard commercial beer with 25 mmol·L<sup>-1</sup> of added sodium [Beer+25]. Over a 1h period following exercise subjects consumed 150% of the total fluid volume lost during exercise. Measures of net fluid balance, urine production, breath alcohol concentration and subjective ratings of gastrointestinal tolerance were collected hourly as dependent variables across a subsequent 4h rest period.

### Preliminary Testing

Each subject performed an incremental test to exhaustion ( $\text{VO}_2$  peak test) on an electromagnetically braked cycle ergometer (Lode Instruments, Groningen, The Netherlands) to determine  $\text{VO}_2$  peak and Peak Sustainable Power Output (PPO). The  $\text{VO}_2$  peak test protocol and the methods used for determining  $\text{VO}_2$  peak and PPO have been previously described (Desbrow, Minahan, & Leveritt, 2007). Briefly, each test began at 100W and increased in 50W increments every 5min until exhaustion. During the  $\text{VO}_2$  peak test, which typically lasted between 30 and 35min, each subjects' expired air was continuously analysed by a calibrated metabolic measurement system (MedGraphics, Minnesota, USA).

## Training and Dietary Standardisation

Experimental trials were separated by at least 7d and were conducted at the same time of the day in a stable laboratory environment ( $19\pm 2^{\circ}$  C, ~55% relative humidity). Subjects were instructed to refrain from consuming alcohol 48h and caffeine-containing substances for 12h before each experiment. Subjects were also asked to refrain from heavy training 24h prior to each trial and any light training was to be completed by 1200h the day before the experimental trials. Food and exercise diaries were used to examine compliance to these procedures. On arrival at the laboratory (0600h) subjects undertook a breath alcohol compliance check (Alcolizer Technologies Inc, Brisbane, Australia) and a urine specific gravity ( $U_{SG}$ ) measure. In the event of a  $U_{SG}$  recording  $>1.02$  subjects were asked to consume a small amount of water (range 500-1000 mL) until a  $U_{SG} \leq 1.02$  could be established. On confirmation of euhydration a standard breakfast was then supplied which provided approximately  $30 \text{ kJ}\cdot\text{kg}^{-1}$  body mass of energy,  $1\text{g}\cdot\text{kg}^{-1}$  body mass of carbohydrate,  $3.2 \text{ mg}\cdot\text{kg}^{-1}$  body mass of sodium and 125 mL of fluid. The breakfast was designed to provide participants with some food for the subsequent 5-6h testing period whilst minimizing fluid and sodium intakes.

## Experimental Protocol

Following breakfast a 30min rest period was taken before the subjects were instructed to empty their bladder as completely as possible and a nude body mass was measured using a calibrated electronic scale to the nearest 10 g (AND Mercury DX6000). Subjects then commenced exercise dressed in shorts, shoes and disposable coveralls (Kimberly-Clarke Worldwide Inc.) designed to increase the heat and subsequent sweat losses while cycling. Exercise intensity was initially set at 60% of the subject's peak power output aiming to produce a 2% reduction in the subject's body mass. For their first trial subject's cycled for 45min before dismounting, drying with a towel and taking a nude body mass. Subsequent

nude body mass were taken at regular intervals until ~1.8% of the subject's initial body mass was lost at which point the subject stopped cycling to allow the remainder of mass loss to occur throughout the cool down. During all subsequent trials subjects exercised for ~10min less than the total exercise time from the first trial before the first nude body mass was collected. If ~1.8% body mass deficit was not achieved subjects were instructed to continue exercising until this goal was reached. A rest period of 30min occurred after the exercise phase to allow subjects to have a cool shower, return to a cool environment and rest. On completion of this period a final nude body mass was taken to determine the volume of fluid required for consumption during the rehydration phase.

Over the next 60min, the subjects ingested one of the rehydration beverages; the order of treatment was randomized using an incomplete latin square design. The entire beverage volume, equal to 150% of the change in body mass, was divided into four equal parts, each of which was consumed over a 15min period. For the subsequent 4h observation period, subjects remained within the laboratory, and were seated except for essential movements. Trials were conducted in a stable laboratory environment ( $22\pm 2^{\circ}\text{C}$ , 60–70% relative humidity).

#### Test Beverage Preparation

The beverages chosen were manufactured by one commercial brewer and purchased at the same time, to minimise the influence of additional and/or different ingredients throughout production. The manufacturer's reported sodium content of the commercial products were between  $3\text{--}5\text{ mmol}\cdot\text{L}^{-1}$  (subject to slight seasonal variation). The additional sodium was added, in form of sodium chloride, prior to consumption by one of the research team (DM).

## Subjective Measures

Questionnaires were conducted during the rehydration phase of the study looking at both palatability and gastrointestinal (GI) symptoms. The palatability questionnaire was administered with the second and last beverages and consisted of ratings of overall palatability, liking, saltiness, sweetness and tartness. The GI questionnaire consisted of rating of nausea, bloating, heartburn, flatulence, belching, abdominal rumbling and hunger and was conducted prior to the first beverage (baseline), at 15min following the last drink and at hourly intervals until the end of the observation period. All questionnaires responses were quantified using a 20-point scale (GI Scale 0 = No symptoms to 20 = Most severe; Palatability Scale 0 = Total dislike to 20 = Like, extremely).

## Fluid Balance and Breath Alcohol Measures

Total urine loss was calculated from the total accumulated urine output in the period from the commencement of drinking until the end of the observation period (i.e. 5h total). Participants were permitted to urinate as required throughout the observation period. Urine per hour was calculated following requested voiding at the conclusion of each hour throughout this 5h period. Net fluid balance was calculated by subtracting the body mass (post voiding) from the initial body mass. When used across an acute time period, it is proposed that this non-invasive parameter will take into account urinary losses, sweat loss and other insensible losses and arrive at the value of complete hydration status (Armstrong, 2005).

Breath alcohol concentrations were analysed using a police grade Alcolizer LE breathalyser (Alcolizer Pty Ltd., Brisbane, QLD, Australia), which had been recently calibrated by the manufacturer. All breathalyser measurements were taken in duplicate, with a triplicate measure recorded if readings differed by  $\geq 0.005\%$ . The measures were averaged to provide the final assessment of BrAC. Previous research from our laboratory has indicated



the inter-trial coefficient of variation for the breathalyser is 2.5% (Irwin, Goodwin, Leveritt, Davey, & Desbrow, 2012). Participants were not informed of their BrAC measures until after completion of the entire study. As described, an initial breath alcohol sample was taken to confirm participants reported to the laboratory having completed a period of alcohol abstinence. The second breath alcohol sample occurred 15min after completing the rehydration phase. This short period was used to avoid contamination from alcohol that may have remained within the mouth. Further breath samples were collected at 1, 2, 3 and 4h throughout the observation period. Results are expressed as a percentage.

### Statistical Analysis

Statistical analysis was conducted using Prism 5.03 for Windows (Graphpad Software Inc, La Jolla, CA, USA). One way repeated measures ANOVA was used to determine any variation between trial on initial body weight, percentage dehydration, exercise time, drink palatability and total urine volume. Two way (treatment and time) repeated measures ANOVA was used to compare hourly urinary volume total, net fluid balance and gastro-intestinal comfort. Post hoc analysis (LSD) was performed on all significant *F* ratios. Significant differences were accepted when  $P \leq 0.05$ . All data are reported as means $\pm$ SD.

## Results

### Standardisation Procedures and Exercise Induced Dehydration

All participants arrived at the laboratory and reported compliance with the pre-trial dietary and exercise control conditions. Participants began each trial without detectable breath alcohol and in a hydrated state according to the  $U_{SG}$  threshold. A small but statistically significant variation in initial body mass was evident between the Beer and Beer+25 trials (LightBeer+25 = 86.1 $\pm$ 14.6 kg, LightBeer = 86.3 $\pm$ 14.3 kg, Beer+25 = 87.1 $\pm$ 14.0 kg, Beer = 86 $\pm$ 14.6 kg,  $p = 0.023$ ). Despite this, participants were successful in achieving similar levels

of hypohydration after the exercise protocol in each of the four conditions (LightBeer+25 =  $1.93 \pm 0.29\%$ , LightBeer =  $2.0 \pm 0.25\%$ , Beer+25 =  $1.93 \pm 0.28\%$ , Beer =  $1.99 \pm 0.23\%$ ,  $p = 0.93$ ). Additionally, the mean exercise time required to induce the dehydration did not differ between trials (LightBeer+25 =  $74 \pm 13$  min, LightBeer =  $79 \pm 15$  min, Beer+25 =  $77 \pm 14$  min, Beer =  $73 \pm 16$  min,  $p = 0.86$ ).

#### Alcohol consumption

Volumes of beer consumed varied between subjects according to their initial bodyweight and degree of hypohydration. The mean volume of beer consumed was not different between trials (LightBeer+25 =  $2.47 \pm 0.43$  l, LightBeer =  $2.57 \pm 0.41$  l, Beer+25 =  $2.50 \pm 0.39$  l, Beer =  $2.54 \pm 0.29$  l,  $p = 0.96$ ). This equated to an alcohol intake of  $57 \pm 9$  g (LightBeer+25),  $59 \pm 9$  g (LightBeer),  $120 \pm 19$  g (Beer+25),  $122 \pm 14$  g (Beer) per trial. Due to volume tolerance issues some subjects required slightly longer than the allocated 1h time period to consume test beverages. The longest required drinking period for all trials was 75min. On all trials where  $>60$ min was required for drink consumption all dependent measures were taken relative to the commencement of drinking. One trial had to be repeated due to fluid loss via emesis.

#### Urine volume and fluid balance

The total urine volumes for each trial are shown in Fig. 1 and the volumes of urine produced per hour for each trial are shown in Fig. 2. Peak urine output occurred throughout the second hour following alcohol ingestion on all trials with the exception of LightBeer+25 where peak urine output occurred throughout the first hour. No statistically significant difference in hourly volumes were observed despite the difference between LightBeer+25 and Beer+25 trials approaching significance 2h after the cessation of drinking ( $p = 0.10$ ). Whole body net fluid balance values for each trial are shown in Fig. 3. A number of subjects

requested to urinate within the drinking period, consequently the post-drinking net fluid balance values are below what could be anticipated given the volume of fluid ingested.

All experimental treatments concluded with participants in a state of negative fluid balance relative to pre-exercise values (LightBeer+25 trial =  $-1.02 \pm 0.40$  kg, LightBeer =  $-1.24 \pm 0.35$  kg, Beer+25 =  $-1.59 \pm 0.32$  kg, Beer =  $-1.64 \pm 0.28$  kg). The consumption of beer with higher levels of alcohol had significantly negative effect on net fluid balance (LightBeer vs Beer  $\sim 0.4$ kg of body mass,  $p = 0.04$ , LightBeer+25 vs Beer+25  $\sim 0.57$ kg of body mass,  $p < 0.01$ ). The net fluid balance results are largely accounted for by higher urine production when consuming higher alcohol beers (LightBeer =  $1757 \pm 412$  mL vs Beer =  $2175 \pm 372$  mL,  $p = 0.09$ , LightBeer+25 =  $1477 \pm 485$  mL vs Beer+25 =  $2101 \pm 482$  mL  $p = 0.014$ ). The addition of sodium to low alcohol beer tended to reduce the average total urine output (LightBeer+25 =  $1477 \pm 485$  mL vs LightBeer =  $1757 \pm 412$  mL), yet the difference was not statistically significant when analysed as total urine or net fluid balance (total urine  $p = 0.25$ , net fluid balance  $p = 0.26$ ). At higher concentrations of alcohol (i.e. Beer vs Beer+25) the addition of sodium had no obvious influence on total urine production or net fluid balance (total urine  $p = 0.75$ , net fluid balance  $p = 0.77$ ). When considered in combination, the reduction of alcohol and the addition of sodium (i.e. LightBeer+25 vs Beer) significantly reduced urine volumes and improved net fluid balance (total urine  $p < 0.01$ , net fluid balance  $p < 0.01$ ). The effect on net fluid balance was evident within 3h of observation.

#### Breath alcohol concentrations

The mean breath alcohol measures for each of all trials are shown in Fig 4. Peak breath alcohol values were recorded 15min after the cessation of drinking on all trials. As expected, the higher concentration beers produced significantly greater breath alcohol values ( $p < 0.01$ ) compared to the lower concentration beer trials. There were no differences in

hourly breath alcohol values observed between trails with similar alcohol concentrations (i.e. LightBeer vs LightBeer+25 or Beer vs Beer+25,  $p > 0.05$  for all comparisons).

### Subjective ratings

No statistically significant differences were observed for any gastro-intestinal rating other than hunger which increased significantly throughout the observation period independent of drink treatment (mean of all trials  $6.4 \pm 5.9$  prior to drinking vs  $15.9 \pm 5.7$  following 4h observation ( $p < 0.01$ )). Ratings of drink saltiness increased to the same extent for both drinks containing added sodium and was independent of time (LightBeer and Beer  $5.6 \pm 4.7$  vs LightBeer+25 and Beer+25  $12.7 \pm 4.4$  following 2<sup>nd</sup> drink,  $p < 0.01$ ). Despite the change in taste no other statistically significant differences were observed for any other palatability rating.

### Discussion

The current investigation examined the concurrent effect of altering the sodium and alcohol content of commercial beer on its potential to influence fluid retention following exercise-induced fluid loss. The principle finding supports our hypothesis, in that, reducing the alcohol concentration and raising the sodium content of beer resulted in significantly greater post exercise fluid retention compared to drinking a commercial full strength beer.

Reducing the alcohol content of beer alone had a significant positive impact on eventual net fluid balance. The only other previous experiment to have investigated the impact of different doses of alcohol on fluid retention following exercise observed similar results (Shirreffs & Maughan, 1997). Despite only including 6 participants this investigation indicated that beverages containing  $\leq 2\%$  ABV are likely to have a negligible diuretic effect compared to a 4% ABV beverage when consumed following exercise (Shirreffs & Maughan, 1997). Collectively, it appears then, that beers containing  $\geq 4\%$  alcohol are likely to induce greater urine outputs, impairing an individual's capacity to replace fluid losses.

The addition of sodium to low alcohol beer appeared to induce a fluid conservation that was not evident when the same amount of sodium was added to the full strength beer. Whilst this result failed to reach statistical significance, when sodium was added to the low alcohol beer participants conserved on average a further ~280 mL of fluid. When similar amounts of sodium are added to non-alcoholic fluids provided following exercise significantly greater fluid retention has been observed (Maughan & Leiper, 1995). Thus, it appears that at lower concentrations of alcohol (~2% ABV) the addition of sodium may continue to contribute to improving fluid retention. The potential of sodium, when added to low alcohol beer, to produce effects in a dose dependent manner is yet to be elucidated.

All beverage treatments failed to completely restore fluid balance across the 4h observation period suggesting that beer, irrespective of ingredient profile, is an undesirable post-exercise fluid. However, the influence of any beverage ingredient manipulation on rehydration relative to an absolute measure (such as return to euhydration) needs to be done with caution as the absolute urine output during the observation period is likely be influenced by the drinking rate (bolus vs metered) used to replace the lost fluid. Increases of ~40% in total urine production have been reported with acute large volumes of fluid (bolus drinking) thought primarily due to an endocrine mediated exacerbation in diuresis (Jones, Bishop, Green, & Richardson, 2010; Mitchell, Grandjean, Pizza, Starling, & Holtz, 1994). Given the rapid drinking rates used in the present study a relative comparison between treatments is likely to provide the most reliable interpretation of the influence alcohol +/- added sodium has on post-exercise fluid retention.

Changes in beverage sodium content failed to influence measures of breath alcohol throughout the observation period. The similarity in breath alcohol measures suggests that the addition of sodium to beer does not markedly influence the blood alcohol response curve, although more a rigorous pharmacokinetics investigation would be required for verification.

The addition of sodium also failed to influence measures of palatability or gastro-intestinal tolerance suggesting that mild sodium modifications within beer are likely to have little influence on ad libitum consumption.

Clearly, many athletes are likely to engage in the consumption of beer following exercise regardless of the negative health implications. A low alcohol beer with added sodium may provide a compromise to the hypohydrated athlete following exercise in that it is a beverage with high social acceptance and palatability whilst avoiding the exacerbated fluid losses observed when consuming full strength beer. The emphasis of beverages with lower alcohol contents may also act as a useful harm minimization strategy aimed at the recovering athlete.

In summary, a reduced alcohol beer with added sodium will reduce post-exercise fluid losses compared to full strength commercial beer.

### **Conflict of Interest**

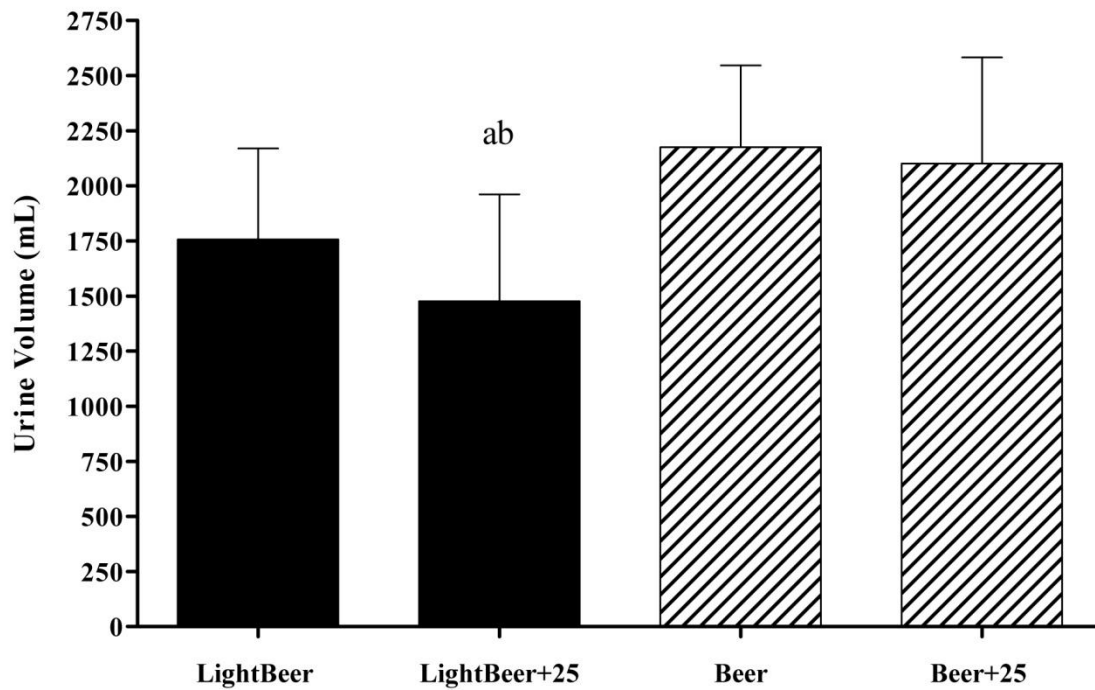
All funding provided by internal Griffith University support. No external funding conflict of interests to disclose. The authors would like to acknowledge the valuable contribution made by all study participants.

## References

- Armstrong, L. (2005). Hydration assessment techniques. *Nutrition Reviews*, 63(6), S40-S54.
- Armstrong, L., Costill, D., & Fink, W. (1985). Influence of diuretic-induced dehydration on competitive running performance. *Medicine and Science in Sports and Exercise*, 17(4), 456-461.
- Burke, L., & Read, R. (1988). A study of dietary patterns of elite Australian football players. *Canadian Journal of Sports Science*, 13(1), 15-19.
- Desbrow, B., Minahan, C., & Leveritt, M. (2007). Endurance cycling performance is unaffected by drink flavor change in trained athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, 17(4), 315-327.
- Devlin, L., Fraser, S., Barras, N., & Hawley, J. (2001). Moderate levels of hypohydration impairs bowling accuracy but not velocity in skilled cricket players. *Journal of Science and Medicine in Sport*, 4(2), 179-187.
- Dietze, P., Fitzgerald, J., & Jenkinson, R. (2008). Drinking by professional Australian Football League (AFL) players: prevalence and correlates of risk. *Medical Journal of Australia*, 189(9), 479-483.
- Ebert, T., Martin, D., Bullock, N., Mujika, I., Quod, M., Farthing, L., . . . Withers, R. (2007). Influence of hydration status on thermoregulation and cycling hill climbing. *Medicine and Science in Sports and Exercise*, 39(2), 323-329.
- Eggleton, M. (1942). The diuretic action of alcohol in man. *Journal of Physiology*, 101, 172-191.
- Hobson, R., & Maughan, R. (2010). Hydration status and the diuretic action of a small dose of alcohol. *Alcohol and Alcoholism*, 45(4), 366-373.
- Irwin, C., Goodwin, A., Leveritt, M., Davey, A. K., & Desbrow, B. (2012). Alcohol pharmacokinetics and risk-taking behaviour following exercise-induced dehydration. [Randomized Controlled Trial]. *Pharmacol Biochem Behav*, 101(4), 609-616. doi: 10.1016/j.pbb.2012.02.016
- Jones, E., Bishop, P., Green, J., & Richardson, M. (2010). Effects of metered versus bolus water consumption on urine production and rehydration *International Journal of Sport Nutrition and Exercise Metabolism*, 20, 139-144.
- Maughan, R., & Leiper, J. (1995). Sodium intake and post-exercise rehydration in man. *European Journal of Applied Physiology*, 71, 311-319.
- Mitchell, J., Grandjean, P., Pizza, F., Starling, R., & Holtz, R. (1994). The effect of volume ingested on rehydration and gastric emptying following exercise-induced dehydration. *Medicine and Science in Sports and Exercise*, 26(9), 1135-1143.
- Mitchell, J., Phillips, M., Mercer, S., Baylies, H., & Pizza, F. (2000). Postexercise rehydration: effect of Na<sup>+</sup> and volume on restoration of fluid spaces and cardiovascular function. *Journal of Applied Physiology*, 89, 1302-1309.
- Moquin, A., & Mazzeo, R. (2001). Effect of mild dehydration on the lactate threshold in women. *Medicine and Science in Sports and Exercise*, 32(2), 396-402.

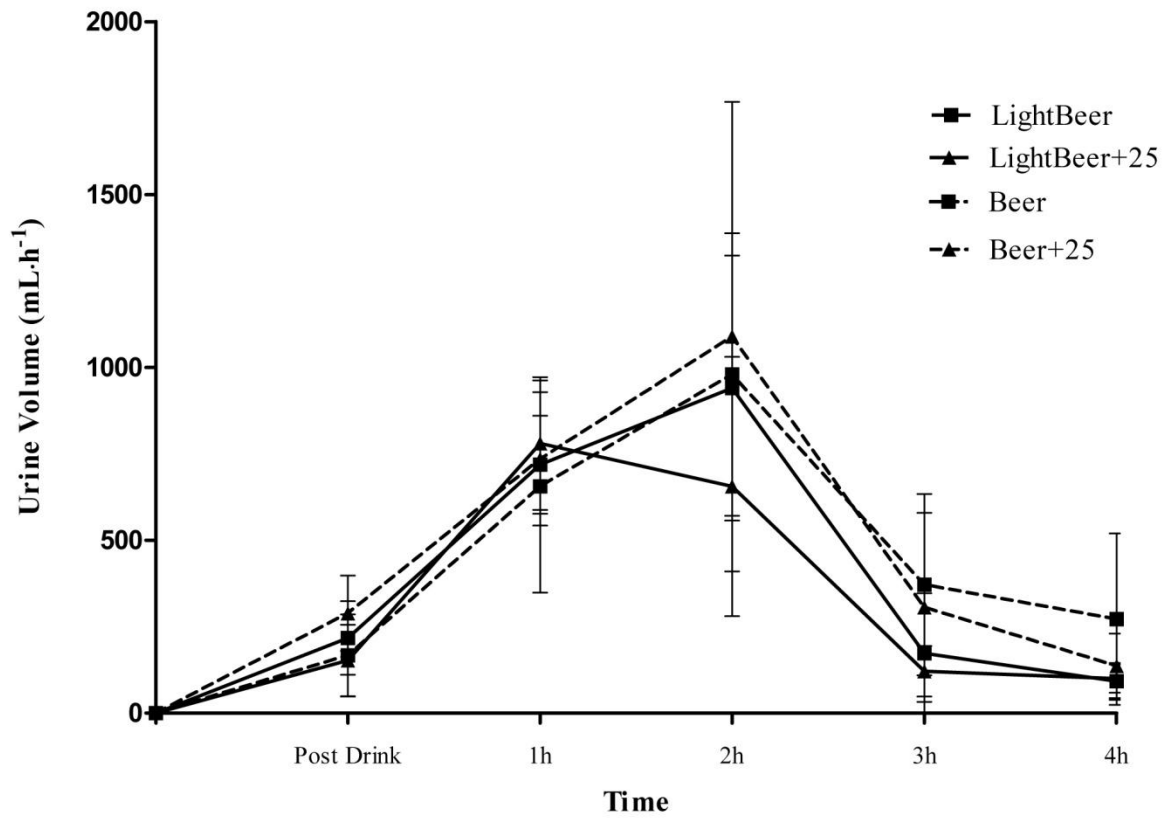
- Murray, M. (1932). The diuretic action of alcohol and its relation to pituitrin. *Journal of Physiology*, 76(3), 379-386.
- Sawka, M., Burke, L., Eichner, E., Maughan, R., Montain, S., & Stachenfeld, N. (2007). American College of Sports Medicine Position Stand. Exercise and fluid replacement. *Medicine and Science in Sports and Exercise*, 39(2), 377-390.
- Shirreffs, S., & Maughan, R. (1997). Restoration of fluid balance after exercise-induced dehydration: effects of alcohol consumption. *Journal of Applied Physiology*, 83(4), 1152-1158.
- Shirreffs, S., Taylor, A., Leiper, J., & Maughan, R. (1996). Post-exercise rehydration in man: effects of volume consumed and drink sodium content. *Medicine and Science in Sports and Exercise*, 28(10), 1260-1271.
- Tomprowski, P., Beasman, K., Ganio, M., & Cureton, K. (2007). Effects of dehydration and fluid ingestion on cognition. *International Journal of Sports Medicine*, 28, 891-896.
- Walsh, R., Noakes, T., Hawley, J., & Dennis, S. (1994). Impaired high-intensity cycling performance time at low levels of dehydration. *International Journal of Sports Medicine*, 15, 392-398.





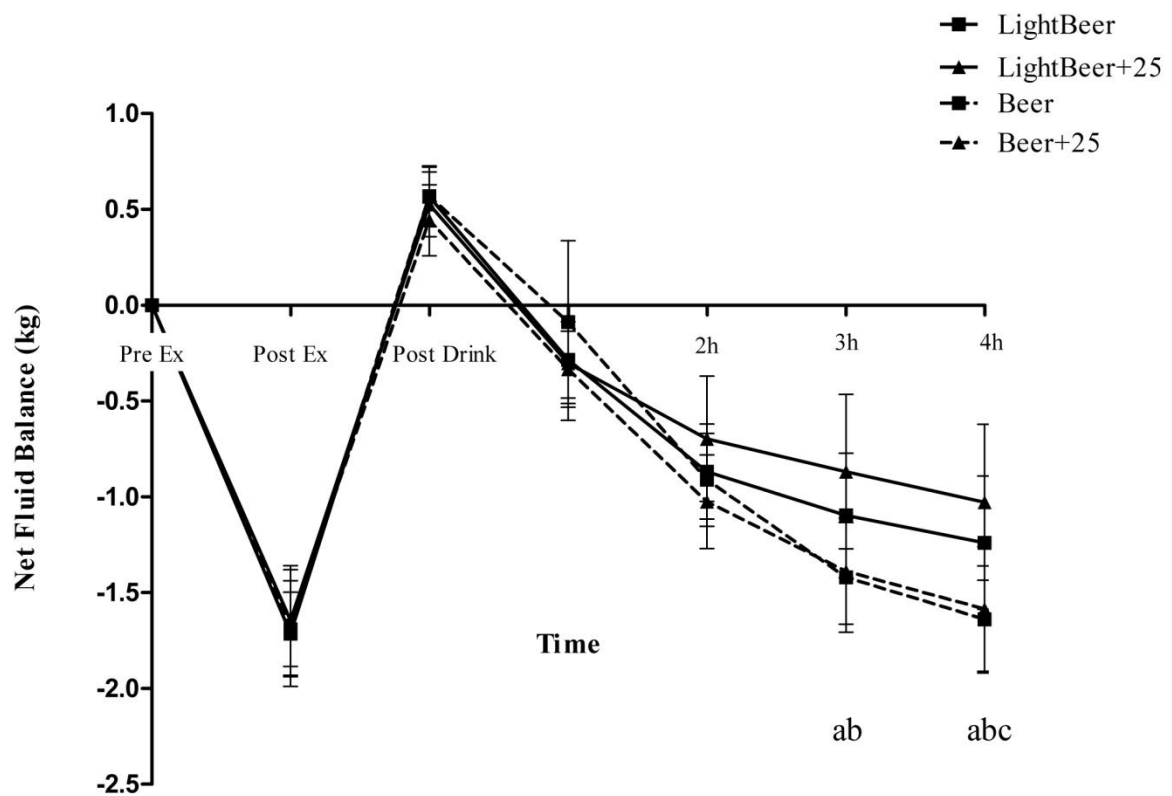
**Figure 1.** The total urine volumes following the 5 hour observation period.

**a** Significant difference between LightBeer+25 vs Beer+25  $p= 0.014$ , **b** Significant difference between LightBeer+25 vs Beer  $p<0.01$ . No other statistically significant differences observed.



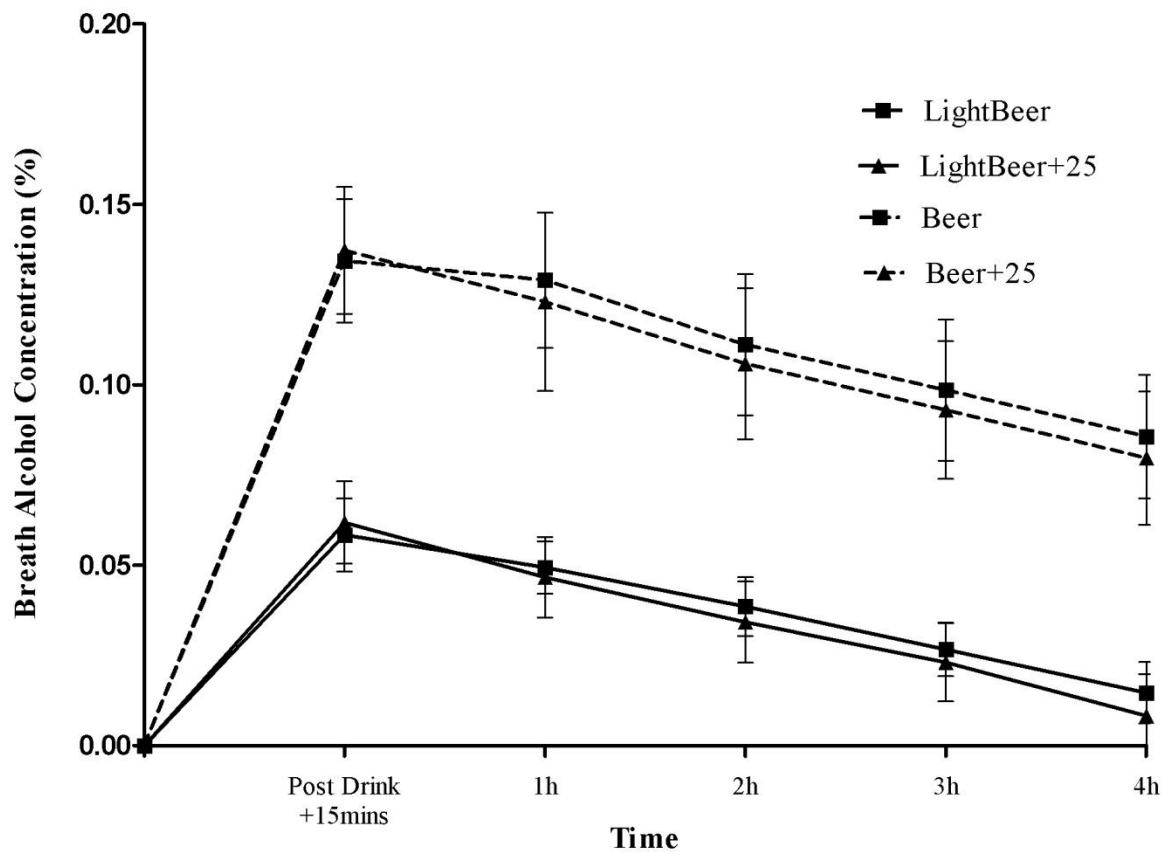
**Figure 2.** Volumes of urine produced per hour throughout the 5 hour observation period.

No statistically significant differences observed.



**Figure 3.** Net fluid balance calculated by change in body mass throughout the 5 hour observation period.

**a** Significant difference between LightBeer+25 vs Beer+25  $p < 0.01$  at 3h and 4h, **b** Significant difference between LightBeer+25 vs Beer  $p < 0.01$  at 3h and 4h. **c** LightBeer vs Beer  $p = 0.04$ . No other statistically significant differences observed.



**Figure 4.** Breath alcohol concentrations throughout the 5 hour observation period.

No statistically significant differences observed between beverages with the same alcohol concentration.