

Abstract

The addition of 25 mmol·L⁻¹ sodium to low alcohol (2.3% ABV) beer has been shown to enhance post exercise fluid retention compared to full strength (4.8% ABV) beer with and without electrolyte modification. This investigation explored the effect of further manipulations to the alcohol and sodium content of beer on fluid restoration following exercise.

Twelve male volunteers lost 2.03±0.19% body mass (mean±SD) using cycling-based exercise. Participants were then randomly allocated a different beer to consume on four separate occasions. Drinks included low alcohol beer with 25 mmol·L⁻¹ of added sodium [LightBeer+25], low alcohol beer with 50 mmol·L⁻¹ of added sodium [LightBeer+50], mid-strength beer (3.5% ABV) [Mid] or mid-strength beer with 25 mmol·L⁻¹ of added sodium [Mid+25]. Total drink volumes in each trial were equivalent to 150% of body mass loss during exercise, consumed over a 1h period. Body mass, urine samples and regulatory hormones were obtained before and 4h after beverage consumption.

Total urine output was significantly lower in the LightBeer+50 trial (1450±183 mL) compared to the LightBeer+25 (1796±284 mL), Mid+25 (1786±373 mL) and Mid (1986±304 mL) trials (all p<0.05). This resulted in significantly higher net body mass following the LightBeer+50 trial (-0.97±0.17kg) compared to all other beverages (LightBeer+25 (-1.30±0.24 kg), Mid+25 (-1.38±0.33 kg) and Mid (-1.58±0.29 kg), all p<0.05). No significant changes to aldosterone or vasopressin were associated with different drink treatments.

The electrolyte concentration of low alcohol beer appears to have more significant impact on post exercise fluid retention than small changes in the alcohol content of beer.

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

Introduction

Acute hypohydration as a result of fluid loss through sweat is commonly experienced by individuals who perform exercise. Replenishment of these exercise-induced fluid losses is well recognised as an important component of the recovery process (Shirreffs et al., 2004). Adequate restoration of fluid loss following exercise may alleviate the impairment in performance and cognitive function that is typically associated with dehydration at levels exceeding 2% of body mass loss (Grandjean & Grandjean, 2007; Lieberman, 2007; Shirreffs, 2009).

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 et al., 2000; Shirreffs et al., 1996). As such, guidelines for recovery following exercise highlight that rehydration strategies should include the replacement of both water and electrolytes (sodium in particular) that are lost via sweat (Sawka et al., 2007). Consuming sodium during the recovery period assists with fluid retention and stimulates thirst, which could assist in promoting a greater fluid intake than loss via urinary output (Shirreffs, 2009). Beverages containing sodium such as sports drinks are well recognised and promoted as suitable post-exercise beverage options. However, many people choose to consume alcoholic beverages after exercise instead, either as part of normal customary routines, the influence of the social atmosphere, or for celebratory reasons (Burke & Read, 1988; Dietze et al., 2008).

The ingestion of alcoholic beverages (beer) after exercise has a tendency to promote increased urine output, facilitating negative fluid balance (Eggleton, 1942; Jones, 1990; Rubini et al., 1955). This is particularly apparent with beer that has high alcohol

concentrations (i.e. full strength beer, >4% Alcohol by Volume (ABV)) and may result from a decline in hormone concentrations responsible for maintaining fluid balance (Shirreffs & Maughan, 1997). The effect appears to be much smaller with the consumption of beer that has a lower alcohol content (i.e. low strength beer, 1% and 2% ABV) (Shirreffs & Maughan, 1997) or when the body is in a state of hypohydration (Hobson & Maughan, 2010). Recently it has been shown that sodium modified (25mmol.L^{-1}) low alcohol beer (2.3% ABV) has greater impact on post exercise fluid retention than full strength beer (with or without electrolyte modification) (Desbrow et al., 2013). In addition, this study also demonstrated that adding sodium to full strength beer did not improve its rehydration potential (Desbrow et al., 2013). Collectively, these studies suggest that the diuretic impact of alcohol is less pronounced after exercise-induced hypohydration and that subtle manipulations of the alcohol and electrolyte concentration of the beverage may influence beer's rehydration potential. However, it is still unclear if an alcohol threshold exists beyond which adding sodium has little impact on fluid retention, and the concentrations of alcohol and sodium within beer which optimise its rehydration potential.

At present, studies examining the rehydration potential of beer following exercise-induced dehydration have compared non-alcoholic, low strength and full strength alcohol varieties, with or without a 25mmol.L^{-1} sodium enrichment. However, no studies have investigated a) the potential to alter the rehydration potential of a mid strength (3.5% ABV) beer via sodium enrichment or b) the impact of increasing the sodium content of low alcohol beer. Whilst full strength beer still appears to have the highest consumption trends over other beer varieties, recent data suggests there has

been a slight decline in consumption of full strength beer and a slight increase in consumption of mid strength beer (Foundation for Alcohol Research and Education, 2013). Furthermore, when sodium has been added to other beverages (e.g. milk), fluid restoration does not always change in a dose dependent manner (Shirreffs et al., 2007). Given the increased popularity of mid strength beer and that beer naturally contains a variety of compounds with the potential to influence rehydration, it would be useful to investigate the potential of mid strength beer and variations in beer's sodium content to influence fluid balance following exercise-induced fluid loss.

Therefore, the aim of this study is to further examine the rehydration properties of beer containing different concentrations of alcohol (2.3% and 3.5% ABV) and electrolytes (no modification, 25mmol.L⁻¹ added sodium, 50mmol.L⁻¹ added sodium). An investigation of fluid balance hormone responses (aldosterone and vasopressin) to different beer solutions will also provide further insight into possible mechanisms responsible for variation in rehydration properties. We hypothesise that a greater concentration of sodium will further enhance fluid retention following low alcohol beer ingestion. Additionally, the rehydration potential of mid strength beer will be unaffected by sodium enrichment.

Methods

Participants

Twelve healthy male recreational athletes [24.2±4.8 y, 75.4±8.1 kg; values are mean±SD] volunteered to participate as participants in the present study. Participants were all non-smokers with an average reported habitual alcohol intake in the 3 months prior to the study ranging from 2.5-450 g·week⁻¹. All participants were fully informed of the nature and possible risks of the study before giving their written informed consent. The investigation was approved by the institutional Human Research Ethics Committee.

Experimental Design

Each subject visited the laboratory on four occasions with the subject's diet and exercise being standardised before each trial. Experimental trials consisted of exercise-induced weight loss (target 2.0% body mass) followed by consumption of a test beverage containing either 1) a low alcohol beer (XXXX Light[®], 2.3% ABV, 2.6 g·100mL⁻¹ CHO, 99 kJ·100mL⁻¹) with 25 mmol·L⁻¹ of added sodium [LightBeer+25], 2) a low alcohol beer (XXXX Light[®]) with 50 mmol·L⁻¹ of added sodium [LightBeer+50], 3) a mid strength beer (XXXX Gold[®], 3.5% ABV, 1.9 g·100mL⁻¹ CHO, 121 kJ·100mL⁻¹) [Mid] or 4) a mid strength beer (XXXX Gold[®]) with 25 mmol·L⁻¹ of added sodium [Mid+25]. Total drink volumes in each trial were equivalent to 150% of body mass loss during exercise, consumed over a 1h period. The order of beverage treatment was randomised using an incomplete latin square design. Measures of net fluid balance, urine production, breath alcohol concentration,

hormone concentrations and subjective ratings of gastrointestinal tolerance were collected as dependent variables across a subsequent 4h rest period.

Exercise 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 ($19\pm 2^{\circ}\text{C}$, $\sim 55\%$ relative humidity). Participants were instructed to refrain from consuming alcohol for 48h and caffeine-containing substances for 12h before each experiment. Participants were also asked to refrain from heavy exercise 24h prior to each trial and any light exercise was to be completed by 1200h the day before the experimental trials. Finally, participants were encouraged to drink fluid throughout the day but instructed to cease food and fluid consumption from 2100h on the evening prior to trials. Food and exercise diaries were used to record their diet/exercise habits prior to the first trial and then to encourage repetition of these behaviours prior to subsequent trials. On arrival at the laboratory (0600h) subjects verbally confirmed compliance to pre-trial diet and exercise procedures and 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 $U_{\text{SG}} \leq 1.02$ could be established. On confirmation of euhydration a standard breakfast consisting of fruit bread, jam and apple juice 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 minimising fluid and sodium intakes.

Experimental Protocol

Following breakfast a 30min rest period was taken before the participants 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). Participants 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. From this point the exercise intensity was self-selected. Subsequent nude body mass measurements 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 participants exercised using the same intensities established within the first trial for ~10min less than the total exercise time before the first nude body mass was collected. If ~1.8% body mass deficit was not achieved participants were instructed to continue exercising until this goal was reached. A rest period of 30min occurred after the exercise phase to allow participants 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 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, participants remained within the laboratory, and were seated except for essential movements.

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 3-5 mmol·L⁻¹ (subject to slight seasonal variation). The additional sodium was added, in the form of sodium chloride, prior to consumption by one of the research team (DC).

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 acceptance, liking of flavour, saltiness, sweetness and tartness. The GI questionnaire consisted of rating 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 questionnaire 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, with urine collected into pre-weighed containers. Hourly urine output 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 (BrAC) 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 et al., 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.

Blood Sampling and Hormone Measures

Blood samples for the determination of aldosterone and arginine vasopressin (AVP) were collected via venipuncture immediately before exercise, immediately after exercise, and then at 1h and 4h of the observation period. Blood samples were immediately decanted into EDTA tubes prior to being placed on ice. Blood plasma was then separated by centrifugation (Sigma 3K10) at 3000rpm for 10 minutes at 4°C. Plasma was then extracted and stored at -84°C until analysis.

Aldosterone and AVP were analysed using enzyme immunoassay (EIA) kits (Cayman Chemicals, USA) and was conducted according to manufacturer's specifications.

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 body mass change, exercise time, drink palatability and total urine volume. Two way (treatment and time) repeated measures ANOVA was used to compare urinary volume total, net fluid balance, plasma Aldosterone and AVP and subjective questionnaire ratings. Post hoc analysis (Bonferroni) was performed on all significant *F* ratios. Significant differences were accepted when $P \leq 0.05$. All data are reported as mean±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. In eleven of the forty-eight total trials participants were required to consume a bolus of fluid in order to meet the pre-determined euhydration threshold. A small but statistically significant variation in initial body mass was evident between the LightBeer+25 and Mid+25 trials (LightBeer+25 = 75.2 ± 8.0 kg, LightBeer+50 = 74.6 ± 8.5 kg, Mid = 75.1 ± 8.1 kg, Mid+25 = 74.6 ± 7.8 kg, $p = 0.01$). Despite this, participants were successful in achieving similar relative levels of hypohydration after the exercise protocol in each of the four conditions (LightBeer+25 = $2.03 \pm 0.2\%$, LightBeer+50 = $2.04 \pm 0.2\%$, Mid = $2.05 \pm 0.2\%$, Mid+25 = $1.98 \pm 0.2\%$). Additionally, the mean exercise time required to induce the dehydration did not differ between trials (LightBeer+25 = 82 ± 17 min, LightBeer+50 = 82 ± 19 min, Mid = 77 ± 15 min, Mid+25 = 80 ± 14 min).

Alcohol consumption

Volumes of beer consumed varied between participants according to their initial bodyweight and degree of hypohydration. The mean volume of beer consumed was not different between trials (LightBeer+25 = 2.29 ± 0.31 l, LightBeer+50 = 2.28 ± 0.29 l, Mid = 2.31 ± 0.34 l, Mid+25 = 2.22 ± 0.36 l). This equated to an alcohol intake of ~53g (LightBeer+25), ~52g (LightBeer+50), ~81g (Mid), ~78g (Mid+25) per trial. All participants were able to consume the required beverage volumes within the allocated drinking period.

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 first hour in all trials. Significantly larger hourly urine volumes (~200 mL) were observed on the Mid and Mid+25 trials compared to the LightBeer+50 trial during the second hour of the observation period. The increased urinary loss continued over the next hour but only for the Mid trial (all values, $p < 0.01$). Only small urine outputs were recorded during the final hour of the observation period (~100 mL) and no difference between trials was evident.

Whole body net fluid balance values for each trial are shown in Fig. 3. All experimental treatments concluded with participants in a state of negative fluid balance relative to pre-exercise values (LightBeer+50 trial (-0.97 ± 0.17 kg), LightBeer+25 (-1.30 ± 0.24 kg), Mid+25 (-1.38 ± 0.33 kg) and Mid (-1.58 ± 0.29 kg)). Significantly improved net fluid balance occurred on the LightBeer+50 compared to the Mid trial 2h following drink consumption. Thereafter all beverage treatments produced significantly lower net fluid balance values when compared to LightBeer+50 (all $p < 0.05$ compared to LightBeer+50). These differences can be largely accounted for by the lower urine output observed following consumption of the beer with the greater sodium concentration (LightBeer+50 = 1450 ± 183 mL, LightBeer+25 = 1796 ± 284 mL, Mid+25 = 1786 ± 373 mL and Mid = 1986 ± 304 mL trials (all $p < 0.05$ compared to LightBeer+50)). No other differences in net fluid balance were observed between beverages.

The consumption of higher levels of alcohol within a sodium enriched beer had no effect on net fluid balance (LightBeer+25 vs Mid+25 >0.1 kg of body mass, $p = 0.44$). The addition of sodium to a mid-strength beer tended to reduce the average total urine output (Mid+25 = 1786 ± 373 mL vs Mid = 1986 ± 304 mL), yet the difference was not statistically significant when analysed as either total urine or net fluid balance (total urine $p = 0.09$, net fluid balance $p = 0.13$).

Breath alcohol concentrations

The mean breath alcohol measures for 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. No significant differences were observed between the trials with the same alcohol concentrations (all values, $p > 0.05$).

Hormone measures

Due to blood sampling complications complete hormonal analysis was only possible for 10 participants. Mean plasma aldosterone and AVP concentrations for all trials are shown in Fig 5. Hormone values indicated only minor changes, which were evident at the post-exercise period and therefore did not appear to be influenced by beverage treatments.

Subjective ratings

No statistically significant differences were observed for any gastrointestinal rating other than hunger which increased significantly throughout the observation period independent of drink treatment (mean of all trials 5.3 ± 4.2 prior to drinking vs 14.6 ± 4.9 following 4h observation ($p < 0.01$)). Overall ratings of drink acceptance and liking of flavour differed by drink treatment independent of time with the LightBeer+50 being significantly less acceptable overall and having a less enjoyable flavour than the LightBeer+25 and Mid beverages at both time points (mean of overall acceptability at both time points, LightBeer+50 = 8.0 ± 5.3 , LightBeer+25 = 12.5 ± 2.9 , Mid = 11.7 ± 3.4 , Mid+25 = 10.5 ± 3.0 ($p < 0.05$)). No difference between LightBeer+50 and Mid+25 were observed for overall palatability. Whilst a trend towards higher ratings of drink saltiness was observed in beverages with added sodium no significant effect of treatment or time was detected (mean of both time points, LightBeer+50 = 12.8 ± 4.7 , LightBeer+25 = 9.9 ± 4.6 , Mid = 7.5 ± 6.1 , Mid+25 = 10.7 ± 4.1 (all values, $p > 0.05$)). No other statistically significant differences were observed for any other reported gastrointestinal or palatability variable.

Discussion

The current investigation further examines the 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 indicates that the greatest fluid retention occurred with the consumption of beer containing the highest electrolyte content combined with the lowest concentration of alcohol. Furthermore, small increases in the alcohol content of sodium enriched beer appear to have little impact on fluid balance following exercise.

Consistent with the findings from our previous experiment (Desbrow et al., 2013), all beverage treatments failed to completely restore fluid balance across the 4h observation period. This suggests that beer, irrespective of ingredient profile, is unlikely to provide a sufficient stimulus for complete rehydration when consumed in isolation after exercise. However, a beer containing 2.3% ABV when combined with $50 \text{ mmol}\cdot\text{L}^{-1}$ of added sodium was a more effective rehydration solution than the same beer with half the sodium content (which was the most effective rehydration solution in our previous experiment) or mid strength beer with or without $25 \text{ mmol}\cdot\text{L}^{-1}$ of added sodium. This result indicates that unlike some other beverages (e.g. milk) (Shirreffs et al., 2007) low and mid strength alcohol beer appears sensitive to manipulations in sodium concentration. This suggests that the total nutrient profile of a beverage may influence sodium's capacity to manipulate a beverage's rehydration potential.

The design of the current investigation required participants to consume predetermined volumes of beverages in accordance with rehydration guidelines (Sawka et al., 2007).

While the consumption of alcohol by athletes and manual labourers remains popular (Grunseit et al., 2012; Irwin et al., 2013; Sonderlund et al., 2014), beer is typically consumed *ad libitum* after exertion. Within this context, the total volume and rate of consumption are likely to be lower than employed in the present study. Furthermore, drinking patterns are likely to be influenced by a range of factors such as thirst, palatability, gastrointestinal tolerance and the perceived consequences of consuming alcohol (Irwin et al., 2013; Minehan et al., 2002; Passe et al., 2000). The subjective results from the present study indicated that the overall acceptance of a beer containing 50 mmol·L⁻¹ of added sodium was lower than reported for all other beverage treatments. This suggests that the addition of large amounts of sodium to beer for rehydration purposes may compromise the intake volume when consumed *ad libitum*. Investigations into the drinking behaviour (rate and volume of consumption) of individuals exposed to beer with a variety of sodium concentrations and/or flavour profiles in comparison to other beverages within an *ad libitum* setting is warranted.

Results from the present study indicated that modifications to the sodium and alcohol content of beer did not influence hormonal concentrations associated with fluid homeostasis. This result is in agreement with the findings of Shirreffs et al (1997) who found no differences in AVP concentrations following the consumption of beer with varying alcohol contents ranging from 0-4% ABV provided to dehydrated individuals. To our knowledge this is the first study to investigate aldosterone responses of dehydrated individuals to beer with varying ingredient profiles. Collectively, the results indicate that improvements in net fluid balance associated with modifications to the ingredient profile of beer do not appear to be related to detectable changes in AVP or aldosterone.

Clearly, many athletes are likely to engage in the consumption of alcohol containing beer following exercise regardless of the negative health implications. As such, the current study was designed to investigate factors within alcoholic beer that may have the potential to influence post-exercise fluid replacement (i.e. a harm minimization approach) and did not seek to compare these manipulations to strategies aimed at optimizing fluid replacement (e.g. via non-alcoholic beverages). The collective results from the present and former research study (Desbrow et al., 2013) indicate that a combination of low alcohol content and the highest tolerable sodium concentration are important components to consider in order to maximise beer's rehydration effectiveness. While the polyphenols within non-alcoholic beer have shown the potential to offer health benefits following endurance exercise (Scherr et al., 2012), the emerging evidence concerning the effect of alcohol on muscle metabolism and function during recovery from exercise impact upon the potential of alcoholic beer to become a preferred recovery beverage (Barnes et al., 2012; Murphy et al., 2013; Parr et al., 2014).

In summary, the consumption of beer containing high sodium combined with low alcohol concentrations can improve fluid retention after exercise. In addition, the electrolyte concentration of a commercial low alcohol beer appears to have more significant impact on post exercise fluid retention than small changes in the alcohol content of beer.

Acknowledgements and Conflict of Interest

The study was designed by BD and ML; data were collected and analyzed by all authors; data interpretation and manuscript preparation were undertaken by BD, ML and CI. All authors approved the final version of the paper. 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.
- Barnes, M. J., Mundel, T., & Stannard, S. R. (2012). The effects of acute alcohol consumption on recovery from a simulated rugby match. *Journal of Sports Sciences*, 30(3), 295-304. doi: 10.1080/02640414.2011.637949
- Burke, L. M., & Read, R. S. (1988). A study of dietary patterns of elite Australian football players. *Canadian Journal of Sports Sciences*, 13(1), 15-19.
- Desbrow, B., Murray, D., & Leveritt, M. (2013). Beer as a Sports Drink? Manipulating Beer's Ingredients to Replace Lost Fluid. *International Journal of Sport Nutrition and Exercise Metabolism*, 23(6), 593-600.
- 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.
- Eggleton, M. (1942). The diuretic action of alcohol in man. *The Journal of Physiology*, 101(2), 172-191.
- Foundation for Alcohol Research and Education. (2013). Annual Alcohol Poll: Attitudes and Behaviours. Deakin, ACT.
- Grandjean, A., & Grandjean, N. (2007). Dehydration and cognitive performance. *Journal of the American College of Nutrition*, 26(5 Suppl), 549-554.
- Grunseit, A. C., MacNiven, R., Orr, R., Grassmayr, M., Kelly, B., Davies, D., . . . Bauman, A. E. (2012). Australian athletes' health behaviours and perceptions of role modelling and marketing of unhealthy products. *Health Promotion Journal of Australia*, 23(1), 63-69.
- 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., & Desbrow, B. (2012). Alcohol pharmacokinetics and risk-taking behaviour following exercise-induced dehydration. *Pharmacology, Biochemistry and Behaviour*, 101(4), 609-616. doi: 10.1016/j.pbb.2012.02.016
- Irwin, C., Leveritt, M., & Desbrow, B. (2013). A Hard Earned Thirst: Workplace Hydration and Attitudes Regarding Post-Shift Alcohol Consumption. *Journal of Health, Safety and Environment*, in Press.
- Jones, A. (1990). Excretion of alcohol in urine and diuresis in healthy men in relation to their age, the dose administered and the time after drinking. *Forensic Science International*, 45(3), 217-224.
- Lieberman, H. (2007). Hydration and cognition: A critical review and recommendations for future research. *Journal of the American College of Nutrition*, 26(5 Suppl), 555-561.
- Minehan, M., Riley, M., & Burke, L. (2002). Effect of flavor and awareness of kilojoule content of drinks on preference and fluid balance in team sports. *International Journal of Sport Nutrition and Exercise Metabolism*, 12(1), 81-92.
- Mitchell, J., Phillips, M., Mercer, S., Baylies, H., & Pizza, F. (2000). Postexercise rehydration: effect of Na⁺ and volume on restoration of fluid spaces and cardiovascular function. *Journal of Applied Physiology*, 89, 1302-1309.
- Murphy, A. P., Snape, A. E., Minett, G. M., Skein, M., & Duffield, R. (2013). The effect of post-match alcohol ingestion on recovery from competitive rugby league matches. *Journal of Strength and Conditioning Research*, 27(5), 1304-1312. doi: 10.1519/JSC.0b013e318267a5e9
- Parr, E., Camera, D., Areta, J., Burke, L., Phillips, S., Hawley, J., & Coffey, V. (2014). Alcohol ingestion impairs maximal post-exercise rates of myofibrillar protein synthesis following a single bout of concurrent training. *PLoS One*, 9(2), e88384.
- Passe, D., Horn, M., & Murray, R. (2000). Impact of beverage acceptability on fluid intake during exercise. *Appetite*, 35, 219-229.
- Rubini, M., Kleeman, C., & Lamdin, E. (1955). Studies on alcohol diuresis. The effect of ethyl alcohol ingestion on water, electrolyte and acid-base metabolism. *The Journal of Clinical Investigation*, 34(3), 439-447. doi: 10.1172/JCI103092
- 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.
- Scherr, J., Nieman, D. C., Schuster, T., Habermann, J., Rank, M., Braun, S., . . . Halle, M. (2012). Nonalcoholic beer reduces inflammation and incidence of respiratory tract illness. *Medicine and Science in Sports and Exercise*, 44(1), 18-26. doi: 10.1249/MSS.0b013e3182250dda
- Shirreffs, S. (2009). Symposium on 'Performance, exercise and health' Hydration, fluids and performance. *Proceedings of the Nutrition Society*, 68(1), 17-22.

- 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. *Med Sci Sports Exerc*, 28(10), 1260-1271.
- Shirreffs, S., Watson, P., & Maughan, R. (2007). Milk as an effective post-exercise rehydration drink. *British Journal of Nutrition*, 98(1), 173-180. doi: 10.1017/S0007114507695543
- Shirreffs, S. M., Armstrong, L. E., & Cheuvront, S. N. (2004). Fluid and electrolyte needs for preparation and recovery from training and competition. *Journal of Sports Sciences*, 22(1), 57-63. doi: 10.1080/0264041031000140572
- Sonderlund, A. L., O'Brien, K., Kremer, P., Rowland, B., De Groot, F., Staiger, P., . . . Miller, P. G. (2014). The association between sports participation, alcohol use and aggression and violence: a systematic review. *Journal of Science and Medicine in Sport*, 17(1), 2-7. doi: 10.1016/j.jsams.2013.03.011

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

a Significant difference between LightBeer+50 and all other beverages (all $p < 0.05$). No other differences were observed between beverages.

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

a Significantly larger urine volume on Mid vs LightBeer+50. b Significantly larger hourly urine volumes on Mid+25 vs LightBeer+50 (all values, $p < 0.01$). No further differences were observed.

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

a Significant difference between LightBeer+50 vs Mid $p < 0.05$ 2h, $p < 0.01$ 3h and 4h, b Significant difference between LightBeer+50 vs Mid+25 $p < 0.01$ all values. c Significant difference between LightBeer+50 vs LightBeer+25 $p < 0.05$ 3hr and $p < 0.01$ 4hr. 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.

Figure 5. Mean plasma aldosterone and AVP concentrations throughout the trials.

a Significant difference between LightBeer+50 vs Lightbeer+25 $p < 0.01$. b Significant difference between LightBeer+50 vs Mid $p < 0.05$.









