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Author

Irwin, Christopher, Campagnolo, Nadia, Iudakhina, Elizaveta, Cox, Gregory R, Desbrow, Ben

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FULL TITLE

Effects of Acute Exercise, Dehydration and Rehydration on Cognitive Function in Well Trained Athletes

RUNNING TITLE

Exercise and Hydration: Effects on Cognitive Function

AUTHORS

Christopher Irwin¹, Nadia Campagnolo¹, Elizaveta Iudakhina¹, Gregory R. Cox², Ben Desbrow¹

¹ Menzies Health Institute Queensland, School of Allied Health Sciences, Griffith University, Gold Coast, Queensland, Australia.

² Sports Nutrition, Australian Institute of Sport, Gold Coast, Queensland, Australia.

CORRESPONDING AUTHOR

Christopher Irwin, PhD

Menzies Health Institute Queensland, School of Allied Health Sciences,
Griffith Health Building (G40), 2.85, Griffith University, Gold Coast,
Southport, Queensland, 4222, Australia.

E-mail: c.irwin@griffith.edu.au

Ph: +61 (07) 56787344

Fax: +61 (07) 56780199

ABSTRACT

This study investigated the effects of aerobic exercise, fluid loss, and rehydration on cognitive performance in well-trained athletes. Ten endurance trained males (25 ± 5 yrs; 175 ± 5 cm; 70.35 ± 5.46 kg; VO_{2max} , 62.95 ± 7.20 ml.kg.min⁻¹) lost $\sim 2.5\pm 0.6\%$ body mass via continuous cycling exercise at $\sim 65\%$ peak sustainable power output (60 minutes duration) before consuming different beverages (Water = W1 and W2, Sustagen Sport = SS, Powerade = PD) and food *ad libitum* on four separate occasions. Cognitive function using a four-choice reaction time task (CRT), body mass, fluid consumption volumes, urine samples, and subjective ratings (alertness, concentration, energy) were obtained before and after exercise, and hourly during recovery (for 4 hours). CRT latency was significantly reduced immediately after exercise compared to pre-exercise measures for all trials (W1 = -16 ± 18 ms, W2 = -22 ± 21 ms, PD = -22 ± 22 ms, SS = -19 ± 26 ms). However, this effect was short-lived with subsequent measures not different from pre-exercise values. No difference in CRT accuracy was observed at any time across all trials. Subjective ratings were not different at any time across all trials. Aerobic exercise, hypohydration or an interaction between these two may provide a small cognitive performance benefit. However these effects are temporary and confined to the immediate post-exercise period.

INTRODUCTION

Acute aerobic exercise has been shown to influence cognitive function (Chang, Labban, Gapin, & Etnier, 2012; Etnier, Nowell, Landers, & Sibley, 2006; Etnier et al., 1997; Lambourne & Tomporowski, 2010). However, both beneficial and detrimental effects have been reported, which may reflect methodological differences between studies (i.e. exercise duration, exercise intensity, age, gender and fitness level of participants, the type of cognitive task employed and the timing of cognitive testing relative to exercise) (Chang et al., 2012; Etnier et al., 2006; Etnier et al., 1997; Grego et al., 2004; Lambourne & Tomporowski, 2010; Moore, Romine, O'Connor P, & Tomporowski, 2012; Tomporowski, 2003; Tomporowski & Ellis, 1986).

Findings from a number of meta-analyses indicate that acute exercise has a small, but positive effect on cognitive performance (Chang et al., 2012; Etnier et al., 1997; Lambourne & Tomporowski, 2010). The physiological mechanisms for this are still unclear, but is often linked to acute improvements in mood (Hansen, Stevens, & Coast, 2001; Yeung, 1996) and exercise-induced arousal (Lambourne & Tomporowski, 2010). However, these effects appear to be short-lasting, with benefits usually only observed up to 15 minutes after exercise (Chang et al., 2012; Lambourne & Tomporowski, 2010). Greater positive effects are also typically observed when 10-20 minutes of exercise is performed compared to longer durations (Chang et al., 2012). Prolonged aerobic exercise facilitates increased fluid loss via sweating (Sawka et al., 2007), which could lead to dehydration and may help explain the attenuation in this effect.

Exercise-induced dehydration has a detrimental impact on cognitive performance (Grandjean & Grandjean, 2007), with impairment typically observed when fluid deficits exceed 2% body mass loss (Lieberman, 2007; Shirreffs, 2009). Prolonged exercise protocols are often used in dehydration studies as a means to induce fluid loss (Adan, 2012; Lieberman,

2012; Secher & Ritz, 2012). Despite employing exercise methods, a negative association between dehydration and cognitive performance is still often reported (Masento, Golightly, Field, Butler, & van Reekum, 2014; Secher & Ritz, 2012). Thus, exercise-induced fluid loss may impose greater impairing effects on cognitive function than any small positive impact gained from physical activity.

Studies investigating dehydration and cognitive function usually incorporate multiple trials with different treatment arms or interventions (e.g. different levels of fluid loss, changes in climatic conditions) to determine dose-response effects or the impact of concurrent stressors. Few studies repeat trials, replicating conditions to determine variability in performance. The use of different cognitive tasks is also common in these studies. Reaction time tasks are frequently used because they are easy to develop, understand and relatively quick to administer. They also allow measures of latency and accuracy, or determining if trade-off effects between these variables occur. Reaction time measures have demonstrated sensitivity to the effects of acute exercise (Chang et al., 2012; Tomporowski, 2003) and dehydration (D'Anci, Vibhakar, Kanter, Mahoney, & Taylor, 2009; Szinnai, Schachinger, Arnaud, Linder, & Keller, 2005; Zuri, Cleary, Lopez, Jones, & Moseley, 2004). However, no study has examined the ability to replicate the effects of exercise-induced fluid loss on cognitive performance when all other factors are standardised. This is an important consideration in order to account for normal perturbations as part of day-to-day or trial-to-trial variability in cognitive performance.

Therefore, the aim of this study was to determine the effects of aerobic exercise and the associated fluid losses on cognitive performance. In addition, we examined the impact of recovery using *ad libitum* consumption of different fluids and snack foods on cognitive performance. *Ad libitum* consumption practices were employed to ensure the study possessed high ecological validity. Specifically, the study compares performance changes on a choice

reaction time task before and after acute aerobic exercise in well-trained athletes. Repeatability of the effects was examined across four trials (confined to the immediate period following exercise) and across two trials (over the entire trial duration) where conditions were replicated. We hypothesised that exercise would facilitate cognitive function irrespective of fluid loss, with faster reaction times anticipated immediately after exercise compared to pre-exercise (baseline) measures, with this improvement diminishing thereafter during recovery.

METHODS

Study design

The data reported in this paper is part of a larger project exploring the rehydration potential of different fluids consumed with food in an *ad libitum* setting during post-exercise recovery (Campagnolo et al., 2017). A secondary aim of the project was to examine the effects of aerobic exercise, fluid loss and fluid consumption on cognitive function. The methodology and results presented here are specific to those of the secondary aim.

Study participants

Ten endurance trained (triathletes, runners and/or cyclists) males (25 ± 5 yrs; 175 ± 5 cm; 70.35 ± 5.46 kg; $VO_{2\max}$, 62.95 ± 7.20 ml·kg·min⁻¹) completed the study. All participants provided written, informed consent prior to commencement. The study was approved by the University's Human Research Ethics Committee (HREC: AHS/68/14/HREC).

Experimental design

Participants attended the laboratory on five separate occasions. At the initial visit, a medical screening was completed prior to a $VO_{2\max}$ test for determination of peak sustainable

power output (PPO). Details for the procedures of the $\text{VO}_{2\text{max}}$ test and calculation of PPO are described elsewhere (Desbrow, Minahan, & Leveritt, 2007). Participants then undertook four experimental trials (Figure 1) completed in a randomised (incomplete Latin square), repeated measures, counter-balanced design. Experimental trials were separated by at least 5 days and were conducted at the same time of day in a stable laboratory environment (23°C and 70% relative humidity). In each trial participant's completed steady state exercise prior to the *ad libitum* provision of food and one of three trial beverages (W1, Water Trial 1; W2, Water Trial 2; PD, Powerade; SS, Sustagen Sport). A computerised cognitive function test involving a four-choice reaction time task (CRT) and subjective ratings of alertness, concentration and energy were collected at specified times throughout trials.

INSERT FIGURE 1 ABOUT HERE

Pre-trial standardisation

Prior to experimental trials, participants were advised to abstain from alcohol for 24 hours, caffeine-containing products and moderate-strenuous exercise for 12 hours, and food for at least 10 hours. On the day before the first trial, participants completed a food and exercise diary recording all food and beverages consumed and any exercise completed. A copy was provided to participants enabling them to repeat this on the day prior to all subsequent trials. On the evening prior to each trial, participants were given a standardised meal (energy = approximately $60\text{kJ}\cdot\text{kg}^{-1}$ body mass) to consume, including a Lasagne (Lean Cuisine[®]), garlic bread (Coles) and 600ml Gatorade (Pepsico[®]). Participants were also encouraged to drink 1000ml plain water prior to retiring to bed to assist with waking hydration status.

Experimental procedures

Resting, pre-exercise period

Participants arrived at the laboratory, having fasted and in a rested state between ~0700 and 0800 hours. Compliance to pre-experimental conditions was verbally acknowledged on arrival. A urine sample was collected to calculate urine specific gravity (USG; Palette Digital Refractometer, ATAGO, USA) as an initial measure of hydration status. Participants who recorded a USG reading >1.020 , were considered hypohydrated (Armstrong, 2005) and provided with a bolus of water (500-1000mL) to consume within ~5 minutes, followed by a 30-minute rest period before a subsequent urine sample and USG measure was taken. If USG remained >1.020 the trial was rescheduled. Once a USG reading <1.020 was recorded, participants completed a computerised CRT task and a subjective ratings questionnaire before voiding their bladder completely and having a baseline nude body mass measured (HW-PW200; A&D Company Ltd, Tokyo, Japan).

Exercise dehydration period

Fluid loss was induced by steady state exercise on a cycle ergometer (Lode Excalibur Sport; Lode BV, Groningen, Netherlands) in a temperature (23°C) and humidity (70%) controlled environment. Exercise commenced at 100W for 5 minutes (warm up) before increasing to an intensity corresponding to 65% PPO. Ratings of perceived exertion (RPE) (Borg, 1973) and heart rate were recorded at 10-minute intervals throughout exercise. After ~20 minutes of cycling, exercise intensity was adjusted by ~5-10% for participants who expressed likely volitional exhaustion prior to achieving the required body mass loss. The exercise protocol established was repeated on all subsequent trials. The intention was to induce dehydration equivalent to 1.8% body mass loss. Body mass was measured to determine fluid loss following 60 minutes of exercise. If required, exercise continued in 10-

minute intervals until the desired body mass loss was achieved. A 5-minute cool down at 100W finalised the exercise protocol. At the end of exercise, a measure of exercise duration and nude body mass (following towel drying) was recorded.

Post-exercise recovery period

Once a BW loss ~1.8% was recorded, participants rested quietly for ~15 minutes before completing the same choice-reaction time task and subjective feelings questionnaire. A nude body mass was then collected before participants had a cool shower. After the shower, participants dried themselves thoroughly and a nude body mass measurement was taken.

Participants were then given access to one of three trial beverages, including water, carbohydrate-electrolyte sports drink (Powerade[®], Coca Cola Ltd) or a milk-based liquid meal supplement (Sustagen Sport[®], Nestle) and could consume the beverage *ad libitum* over a four hour recovery period. Access to a variety of snack foods including sports bars, fresh fruit, bread and condiments was also provided, which could be consumed *ad libitum* during the final 15 minutes of hours 1 and 2 in the recovery period. In the final two minutes of each hour of the recovery period participants completed the same CRT test and the subjective ratings questionnaire.

Data collection

Food and fluid intake measures

Fluid volume and total energy (kJ) intake were calculated by weighing foods and beverages before and after each hour to the nearest 1g. All food weights for each participant were measured by one researcher (EI or NC). Food weights were then entered into a spreadsheet (Excel[®], Microsoft Office 2013) developed using manufacturers' values for packaged foods and Foodworks[®] (Version 6.0, 2014, Xyris Software, Australia) for fresh food items.

Duplicate calculations of fluid and total energy consumption from foods and beverages were verified by the same investigators.

Urine sampling

At the end of each hour of recovery, participants completely voided their bladder into an empty container for subsequent measures of hourly and cumulative urine volumes. Participants were permitted to urinate throughout recovery and on each occasion the void was collected and added to the hourly urine output. Total urine loss was calculated from the accumulated urine output from commencement of drinking until the end of the recovery period.

Body mass measures

Nude body mass measures were obtained pre and post exercise and at the end of each hour in recovery (HW-PW200; A&D Company Ltd, Tokyo, Japan). Net body mass was calculated by subtracting the body mass (post voiding) from the initial body mass, with faecal losses excluded via immediate pre–post body mass measurements. When used across an acute time period, body mass changes take into account urinary losses, sweat loss and other insensible losses (Armstrong, 2005).

Net fluid balance

Total fluid retention was calculated by the formula (where x equals 1 or 4 hours):

Fluid retention = [(volume of beverage consumed - urine output after x time) / volume of beverage consumed] \times 100

Cognitive function test

The reaction time test (CRT) involved a four-choice random selection task (Inquisit 4 Lab; Millisecond software, LLC, Seattle, Washington) and was conducted at baseline, post-exercise, and hourly throughout the recovery period. The task involved pressing one of four designated keys on a keyboard corresponding to one of four boxes on a laptop screen, which randomly changed from black to red at various delay signals (between 400ms and 2000ms). The task took approximately two minutes to complete involving a total of 40 recorded trials (latency and accuracy). The first two recordings in each testing session were discarded from overall analysis to account for anticipatory responses and re-familiarisation.

Subjective ratings questionnaire

Adaptive Visual Analogue Scales (AVAS) were used to assess responses to questions including 'how alert are you', 'how well can you concentrate' and 'how energetic do you feel'. All measures were conducted on a 100mm line, with 0mm representing 'not at all' and 100mm representing 'extremely' using a computerised modifiable software program (Marsh-Richard, Hatzis, Mathias, Venditti, & Dougherty, 2009).

Data analysis

Statistical analysis was completed using SPSS for Windows, Version 22.0 (IBM Corp. 2013, USA). Comparisons between trials for baseline measures (body mass and USG) and exercise-induced fluid losses were conducted using one-way repeated measures analysis of variance (ANOVA). Post hoc analysis (Bonferroni) was conducted where significant main effects were present. Results for CRT accuracy and latency for the two identical water trials (W1 and W2) were initially compared using paired samples *t*-tests to examine repeatability. Pearson correlation coefficients (*r*) were calculated to assess test-retest reliability of these

measures. The calculation produces a value between zero and 1; values closer to 1.00 indicate less error variance and stronger reliability. Coefficient of variation (CV) for CRT performance measures was calculated using the mean and standard deviations of the variables at each time point. Two-way repeated-measures ANOVA (trial x time) were used to examine changes in body mass, CRT performance variables (latency and accuracy) and subjective ratings. Post hoc analysis (Bonferroni) was performed on all significant *F* ratios. Repeated measures intervention effect sizes (ES) were calculated as Hedges' *g*. The mean difference between trials in each intervention was standardised against the standard deviation (SD) of the change and corrected for bias due to small sample size (Cohen, 1988; Hedges, 1981) using the supplementary spreadsheet by Lakens (2013). Intra-class correlation coefficient (ICC) for pre-exercise measures of CRT was calculated using the two-way mixed average measures (absolute agreement) model. Variability (CV) for pre-exercise CRT performance measures was calculated across the four trials. Typical error of measurement for pre-exercise CRT performance measures was calculated by dividing the standard deviation of the difference score for each individual by $\sqrt{2}$ as described by Hopkins (2000). Significant differences were accepted as $p < 0.05$. All data are reported as means \pm SD unless otherwise specified.

RESULTS

Standardisation procedures

All participants verbally acknowledged compliance with pre-trial dietary and exercise conditions, except one participant who consumed 250ml of apple juice at 0400 hours on trial 1. This was repeated on subsequent trials to ensure consistency. A number of participants were provided a bolus of plain water (500-1000 mL) pre-trial due to pre-exercise USG values > 1.020 . When water was provided on trial 1 ($n=1$, 1000 mL), this was repeated on all

subsequent trials; otherwise a one-off bolus (500 mL) was provided as required for trials. Overall, only 4 out of 36 trials required the additional small water bolus to be consumed by participants. Prior to commencing exercise all participants produced a urine sample registering a USG <1.020. Pre-exercise measures of body mass and USG for each trial are indicated in Table 1. No significant differences were observed in these measures between trials ($p>0.05$).

INSERT TABLE 1 ABOUT HERE

Exercise measures

Examination of trial order revealed no main effect for fluid loss ($F(3,27)=0.336$; $p=0.799$), indicating that results were not influenced by exercise adaptation. All participants achieved the target fluid loss following 60 minutes of exercise. Mean body mass loss, HR during exercise and RPE for each trial are detailed in Table 2. No differences in body mass loss, $F(3,27)=0.288$; $p=0.834$ or RPE, $F(3,27)=1.385$; $p=0.269$ were observed between trials. There was a significant main effect of trial for average HR, $F(3,12)=6.273$; $p=0.008$, however, post hoc analysis failed to reveal any further significant differences between trials ($p>0.05$). Average HR data indicated that participants performed exercise at an intensity corresponding to ~80% HR_{max} in each of the trials.

INSERT TABLE 2 ABOUT HERE

Fluid intake, retention and urine volume

No main effect of trial order was observed on total ingested fluid volume, $F(3, 27)=0.107$, $p=0.955$. There was also no significant difference in the volume of fluid ingested between the W1 and W2 trials ($p>0.05$). A significant main effect of trial was found for the

volume of beverage ingested, $F(3,27)=7.26$; $p=0.001$. Post hoc analysis revealed greater volumes of beverage ingested during the W1 and PD trials compared to the SS trial ($p<0.05$). There were no differences in fluid volume ingested from food between any of the trials, $F(3, 27)=0.614$, $p=0.612$. The proportion (%) of fluid retained in each trial was W1= $72\pm 8\%$, W2= $73\pm 11\%$, PD= $72\pm 17\%$ and SS= $74\pm 10\%$. There were no significant main effects of trial on the total percentage of fluid retention, $F(1.455, 13.093)=0.086$, $p=0.861$. No significant main effect of trial was found for total urine output, $F(1.276, 11.484)=2.127$, $p=0.171$.

Total energy intake from food and beverages

The total mean energy intake (fluid and food) was 7826 ± 888 kJ, 7578 ± 1112 kJ, 10179 ± 1484 kJ, and 10577 ± 2210 kJ for W1, W2, PD and SS, respectively. Mean energy intake was similar across both water trials ($p=0.550$, CV=9.7%). A significant main effect was observed for total mean energy consumed between trials, $F(3, 27)=14.635$; $p<0.001$; with significantly more energy consumed on PD and SS trials compared to both water trials ($p<0.05$). No difference was observed between PD and SS for mean energy intake ($p>0.05$).

Body mass change

Mean changes in net body mass across each trial are displayed in Figure 2. All participants began the recovery period in a state of negative net body mass relative to pre-exercise values (W1 = -1.71 ± 0.46 kg, W2 = -1.80 ± 0.48 kg, PD = -1.73 ± 0.51 kg, SS = -1.77 ± 0.54 kg; $p<0.05$). A significant main effect of trial on net body mass change was observed during the recovery period, $F(2.005, 18.049)=5.812$, $p=0.011$; however, post hoc analysis failed to reveal any significant differences between trials ($p>0.05$). There was a significant main effect of time on net body mass change during the recovery period, $F(1.857, 16.710)=147.868$, $p<0.001$. Post hoc analysis revealed a significant increase in net body mass

during the first hour of recovery compared to post-exercise values for all trials ($p < 0.05$). Net body mass change decreased significantly in the second hour of recovery for all trials ($p < 0.05$). During the last 2 hours of recovery, no significant changes in net body mass were observed for any of the trials. No trial by time interaction was observed, $F(0.294, 0.147) = 1.993, p = 0.108$.

INSERT FIGURE 2 ABOUT HERE

Cognitive task performance – Repeated water trials

Mean performance values for CRT latency and proportion of correct responses are shown in Figures 3 and 4 respectively. Comparisons between the two identical water trials indicated no significant differences in CRT performance (latency or accuracy) at any time point across the trial (all p 's > 0.05). The degree of variability in individuals' CRT latency between the water trials at each time point were determined as CV's of Pre-Ex = 5.0%, Post-Ex = 4.9%, H1 = 3.0%, H2 = 3.1%, H3 = 5.9%, and H4 = 4.8%. Variability in individuals' CRT accuracy were determined as CV's of Pre-Ex = 1.3%, Post-Ex = 1.5%, H1 = 1.6%, H2 = 1.1%, H3 = 1.1%, and H4 = 1.1%. Moderate to high test-retest reliabilities (Pearson r) for CRT latency were observed across time between the two water trials (Pre-Ex = 0.49, Post-Ex = 0.68, H1 = 0.74, H2 = 0.73, H3 = 0.40, and H4 = 0.66). Small to high test-retest reliabilities for CRT accuracy were observed at each time point (Pre-Ex = 0.33, Post-Ex = 0.67, H1 = 0.22, H2 = 0.73, H3 = 0.70, and H4 = 0.45). The typical error of measurement for CRT latency at each time was Pre-Ex = 27.3, Post-Ex = 23.7, H1 = 16.5, H2 = 14.3, H3 = 29.8, and H4 = 24.7.

Cognitive task performance – All trials

Analysis of pre-exercise values revealed no significant effects of trial order for CRT latency, $F(3, 27)=1.050$, $p=0.386$ or accuracy, $F(3, 27)=1.332$, $p=0.285$, indicating no effect of learning on task performance over the duration of the study. Comparison of pre-exercise values for CRT latency by beverage condition revealed no differences between trials, $F(3, 27)=0.900$, $p=0.454$. A significant moderate ICC of 0.75 (95% CI = 0.35-0.93), $p=0.030$ was calculated for pre-exercise CRT latency measures between trials, indicating excellent reliability for initial measures of this performance variable. The degree of variability in

individuals' CRT latency across trials was determined as a CV of 4.7%. The typical error of measurement in CRT was calculated as 21.8.

Analysis of CRT latency by beverage condition indicated no main effect of trial, $F(3, 27)=1.413$, $p=0.261$ or trial by time interaction, $F(15, 135)=1.019$, $p=0.439$. However, a significant main effect of time was observed, $F(5, 45)=4.727$, $p=0.001$ with post hoc analysis indicating a significant reduction in CRT latency post-exercise compared to pre-exercise for all trial conditions ($W1 = -16\pm 18\text{ms}$, $W2 = -22\pm 21\text{ms}$, $PD = -22\pm 22\text{ms}$, $SS = -19\pm 26\text{ms}$; $p<0.05$). *Hedges g* effect size for change in CRT latency pre to post exercise was calculated as 0.55 (range 0.36 – 0.70). Analysis of CRT accuracy by beverage condition indicated no main effect of trial, $F(3, 27)=0.265$, $p=0.850$; time, $F(5, 45)=2.082$, $p=0.085$ or trial by time interaction, $F(15, 135)=0.795$, $p=0.682$. Participants had a high degree of success (>96% correct) in response selection to stimuli at all testing stages and across all trials.

INSERT FIGURES 3 AND 4 ABOUT HERE

Subjective ratings

No significant differences were observed in subjective ratings of alertness, concentration and energy according to trial, time or trial by time interaction analysis (all $p's>0.05$). On the 0 - 100mm AVAS, levels of alertness ranged between 56 – 80 mm, levels of concentration ranged between 54 – 77 mm and levels of energy ranged between 42 – 73 mm across the trials, with large inter- and intra- individual variations evident.

DISCUSSION

Results from this study indicate an immediate but temporary improvement of choice reaction time in well-trained athletes following acute aerobic exercise, irrespective of fluid

loss. These effects were consistent across four repeated trials that were standardised for exercise mode, intensity, duration, energy expenditure and levels of fluid loss.

Health benefits of regular physical activity, in particular those associated with aerobic exercise have been well established (Warburton, Nicol, & Bredin, 2006) and typically include improvements in physiological (Warburton et al., 2006) and psychological (DiLorenzo et al., 1999) well-being. This also extends to the enhancement of cerebral activities such as improved cognitive function (Etnier et al., 1997; Meeusen, 2014). Whilst positive effects on cognitive function have also been demonstrated with acute bouts of aerobic exercise, this appears to be dependent on factors such as exercise duration and the timing of cognitive test administration, amongst other variables (Chang et al., 2012). One of the limitations of research to date is that, until now, repeatability of cognitive task performance following exercise-induced dehydration had not been exclusively investigated. An understanding of variability in performance on replicated tasks is important because it provides confidence that any effect observed is genuine rather than occurring by chance.

In the present study, CRT latency was improved after a bout of aerobic exercise compared to pre-exercise measures. However, this effect was temporary and confined to the immediate post-exercise period. No difference in the total number of correct responses (CRT accuracy) was observed at any time throughout trials, indicating that participants were able to respond with a high degree of accuracy on all occasions. These effects were replicated across four separate trials, irrespective of fluid loss and fluid consumption variables. Overall, these results suggest that acute aerobic exercise provides immediate cognitive performance benefits, which are not influenced by fluid losses greater than 2% body mass loss. Thus, aerobic exercise appears to provide an immediate positive effect on cognitive function that is greater than any detrimental effect imposed by fluid loss. Our results are consistent with the findings from recent meta-analyses indicating small but positive effects of acute aerobic

exercise on cognitive performance (Chang et al., 2012; Lambourne & Tomporowski, 2010), but challenge studies reporting acute effects of exercise-induced dehydration on cognitive performance (Cian, Barraud, Melin, & Raphel, 2001; Cian et al., 2000; D'Anci et al., 2009; Ganio et al., 2011; Grego et al., 2005).

Improvements in mood and arousal levels are often provided as possible explanations for cognitive enhancements observed with acute exercise (Hansen et al., 2001; Yeung, 1996). The facilitating effect of acute exercise on reaction time specifically is proposed to result from an increase in physiological arousal (Brisswalter, Collardeau, & Rene, 2002; Gutin, 1973; Kamijo et al., 2004; McMorris & Graydon, 1996) and cognitive arousal induced by exercise (Clarkson-Smith & Hartley, 1989). On the other hand, dehydration is generally associated with a deterioration in mood state, which has been shown to influence factors such as concentration and level of alertness (Lieberman, 2007; Shirreffs, 2009). No observable changes in subjective ratings were observed within any of the trials from the present study. Thus, neither exercise, fluid loss nor rehydration had any impact on ratings of alertness, concentration or energy levels. It is possible that any negative effects on mood imposed by dehydration may be counteracted by the positive effects of physical activity, resulting in no change to the subjective variables assessed. However, the participants in this study were well-trained endurance athletes accustomed to the demands of the exercise task employed. It is likely they would be less affected by factors such as fatigue, which may help explain these observations. The same effects may not be true with other population groups such as recreational or non-athletes.

In this study, no effect of rehydration with different beverages was observed on CRT performance. However, it is important to recognise factors that may have influenced these results. Cognitive testing in the recovery period occurred later in the morning and into the early afternoon (~1000, 1100, 1200 and 1300 hrs), whereas pre-exercise and immediate post-

exercise testing only occurred in the early morning (~0730 and 0845 hrs). The largest effects of acute exercise on cognitive performance have been observed when testing occurs in the morning compared to the afternoon or evening/night (Chang et al., 2012). Thus, time of day and changes in circadian rhythm (but also other factors such as boredom, tiredness etc.) as recovery time progressed may confound these results. In addition, we are unable to determine how long the positive effects of acute exercise last over that of dehydration in this study, given that testing throughout the recovery period was completed whilst participants had access to *ad libitum* fluid and food consumption. Future research may use study designs allowing the duration of these effects to be determined by incorporating multiple testing time points following exercise prior to the administration of fluid/food.

Comparing results from studies examining the effects of either acute exercise or dehydration on cognitive performance is difficult due to a lack of methodological consistency between studies. The present study employed a within-subjects experimental design utilising a randomised controlled trial protocol. Participants were all young, healthy, well-trained athletes and performed the same cycling exercise task at an identical relative workload (intensity and duration) across all four trials. Equivalent levels of fluid loss were achieved and cognitive tasks were administered at the same time of the day and at identical times relative to completion of the exercise task across all four trials. The degree of control and standardisation applied in the present study strengthens the repeated observations that indicate a small but beneficial effect of acute aerobic exercise on cognitive performance. However, only a single cognitive task measuring choice reaction time was employed in this study. The same effects may not be observed with other cognitive tasks, particularly where different cognitive domains are involved (e.g. memory, executive function, information processing etc.). Future research employing a range of cognitive tasks across a number of cognitive domains would clarify these effects. Furthermore, we can not directly rule out any

influence exercise-induced fluid loss may have contributed to the cognitive performance benefits observed. Whilst it is unlikely (based on previous reports) that exercise-induced dehydration would confer a positive effect on cognitive function, this study did not include a trial where euhydration was maintained during exercise. Thus, some of the effects observed may be related to fluid loss or an interaction between exercise and hypohydration. Using fMRI techniques, Kempton and colleagues (2011) observed increases in blood oxygen level dependent (BOLD) response and a higher level of neuronal activity, enabling healthy adolescent subjects to complete a cognitive task with no performance deficit following exercise-induced dehydration. Given that the participants in the present study were well-trained athletes, accustomed to high-intensity exercise and the associated fluid losses, it is possible that hypohydration resulted in greater neuronal activity that moved beyond compensatory activity, contributing to the enhancements in cognitive function observed. Acute exercise itself has been thought to promote cognitive function via enhancement of mood (Hansen et al., 2001; Yeung, 1996) and exercise-induced arousal (Lambourne & Tomporowski, 2010). Furthermore, enhanced metabolic activity (increased blood glucose delivery) may have also contributed to the cognitive performance benefits observed (Benton, 2011).

The results of this study suggest that well-trained athletes involved in acute aerobic exercise may not suffer cognitive impairment in the immediate post-exercise period, despite substantial fluid losses that may occur with endurance exercise. In fact, these athletes may have a small positive cognitive benefit induced by exercise irrespective of fluid loss. Whilst others have reported negative impacts of dehydration on cognitive function (Adan, 2012; Grandjean & Grandjean, 2007; Lieberman, 2007; Lieberman, 2010; Secher & Ritz, 2012) and athletes are often advised to consume enough fluid immediately after exercise to counteract losses, aggressive post-exercise fluid consumption regimens may not be warranted to ensure

cognitive function is retained. From a practical perspective, it may be more appropriate for athletes to adhere to American College of Sports Medicine fluid recovery guidelines (Sawka et al., 2007) and when possible, consume fluids over an extended time period. Employing this fluid recovery strategy is not likely to negatively impact on cognitive function and will also maximise opportunities for fluid retention.

In summary, this investigation demonstrates that acute aerobic exercise, hypohydration, or an interaction between these two may provide positive cognitive benefits. However, these positive effects appear to be small and temporary; confined to the immediate post-exercise period.

TABLES

Table 1. Pre-exercise measures for each trial ($n=10$)

Measure	Trial				P value
	W1	W2	PD	SS	
BM (kg)	70.33 ± 5.79	70.48 ± 5.78	70.04 ± 5.47	70.59 ± 5.61	0.091
USG	1.011 ± 0.007	1.013 ± 0.007	1.016 ± 0.017	1.010 ± 0.005	0.441

BM, body mass; USG, urine specific gravity; W1, water 1; W2, water 2; PD, Powerade; SS, Sustagen Sport.

Values are Mean ± SD.

Table 2. Mean exercise measures for each trial ($n=10$)

Measure	Trial			
	W1	W2	PD	SS
Average HR (bpm)	155 ± 15	160 ± 14	161 ± 12	157 ± 14
RPE (Borg 6-20)	15.3 ± 1.5	14.7 ± 1.3	15.4 ± 1.2	15.0 ± 1.1
Body mass loss (%)	2.43 ± 0.59	2.53 ± 0.57	2.47 ± 0.70	2.50 ± 0.68

HR, heart rate; RPE, rating of perceived exertion; W1, water 1; W2, water 2; PD, Powerade; SS, Sustagen Sport.

Values are means ± SD.

FIGURES

Figure 1.

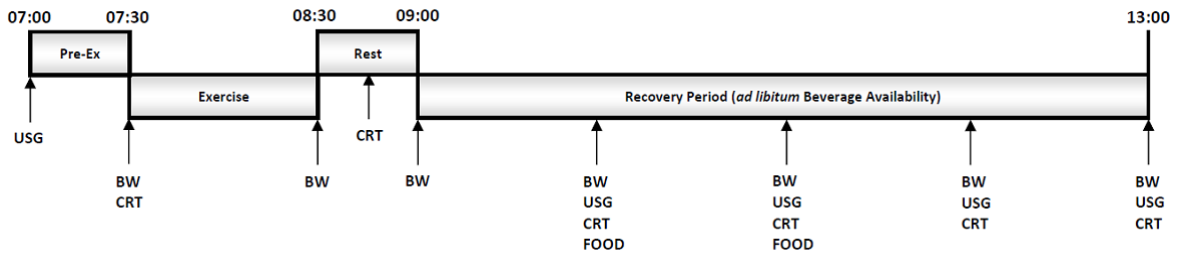


Figure 2.

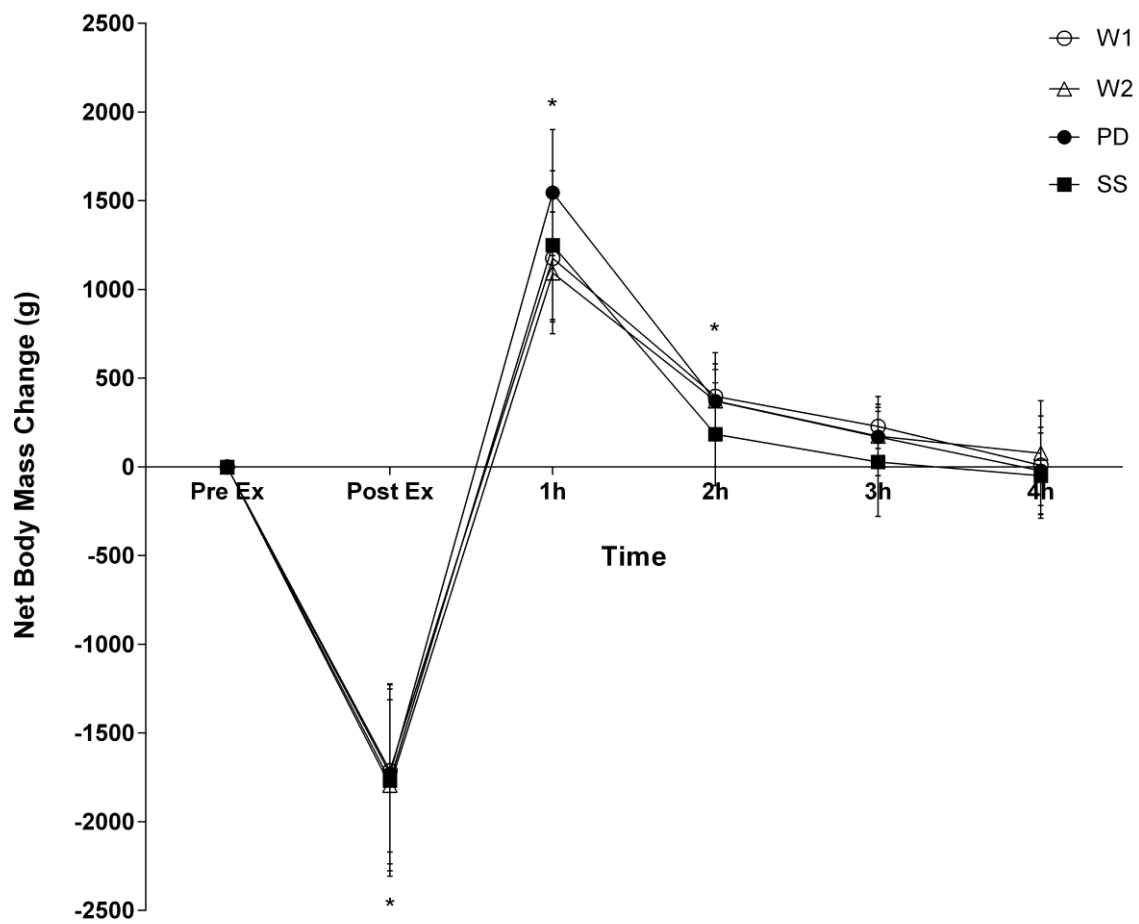


Figure 3.

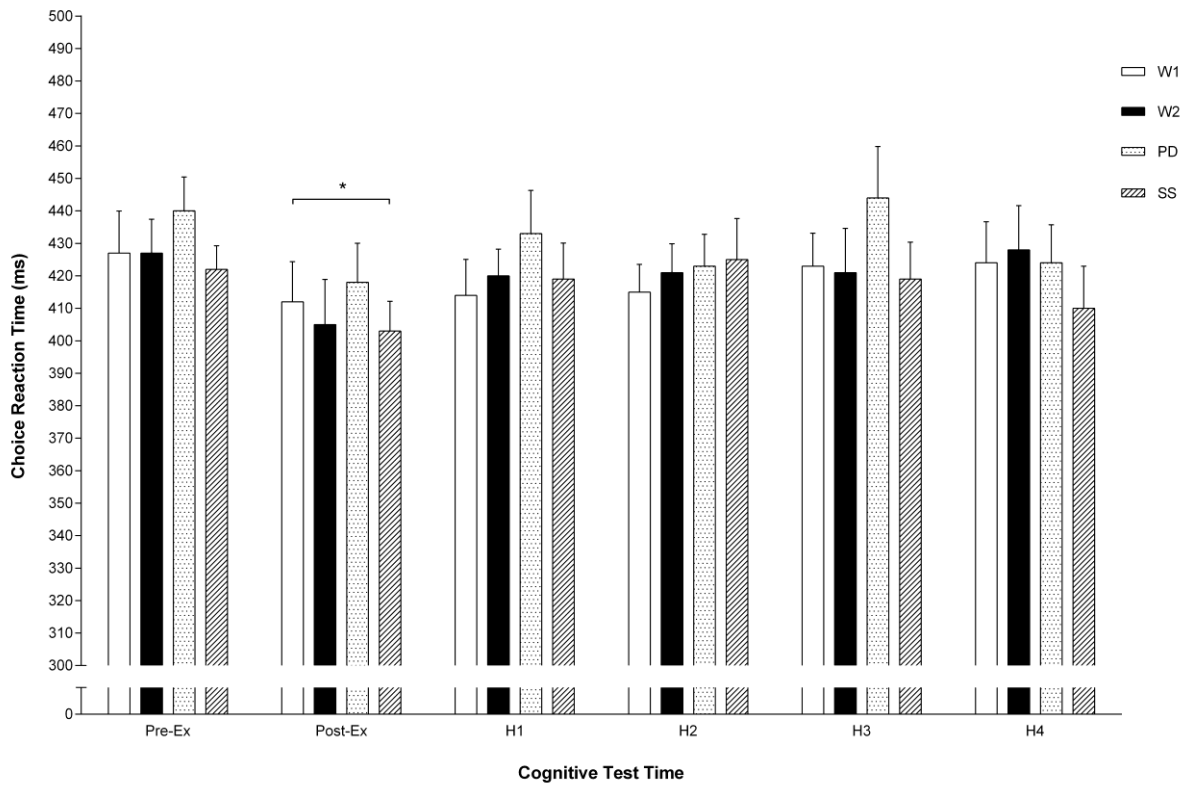
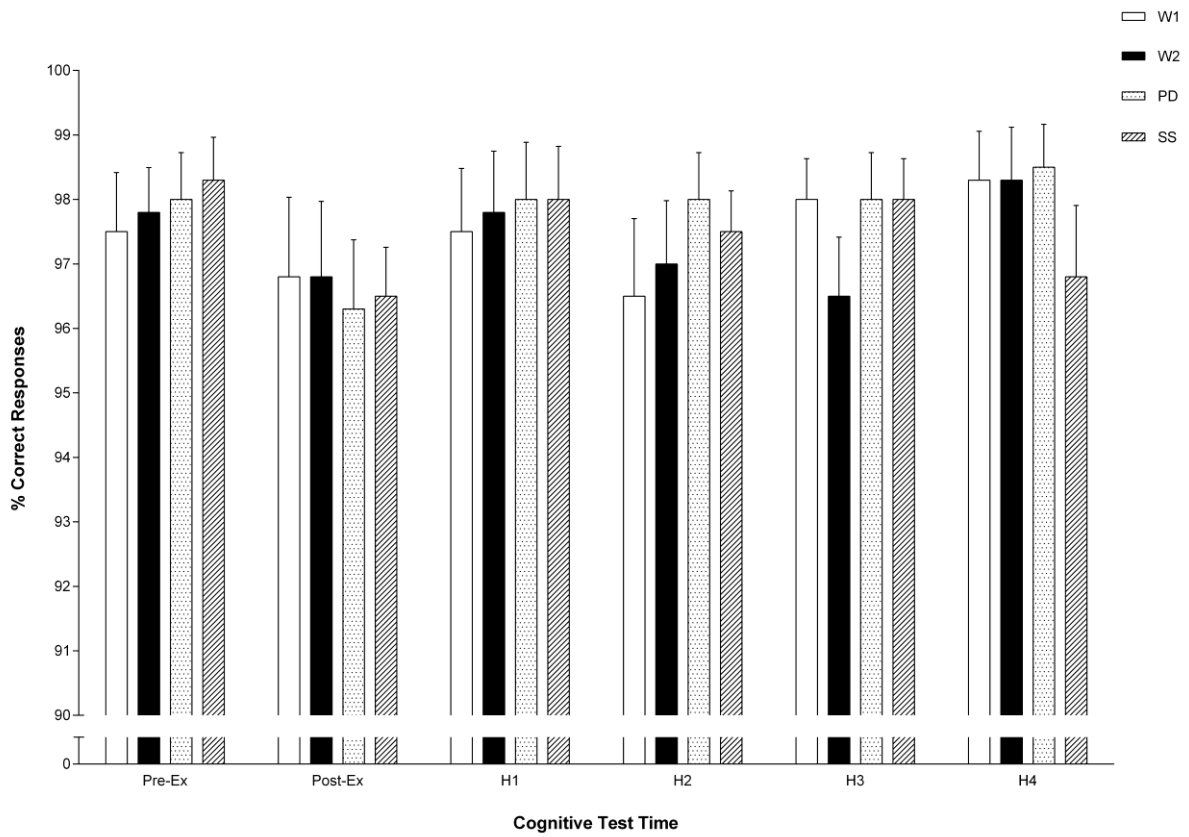


Figure 4.



1 **FIGURE CAPTIONS**

2

3 **Figure 1.** Schematic of experimental trial protocol. Pre-Ex, Pre-Exercise; BW, Nude body
4 weight; USG, Urine specific gravity; CRT, Choice Reaction Time cognitive task; SRQ,
5 Subjective Ratings Questionnaire; FOOD, *ad libitum* access to snack foods for prior 15
6 minutes; W1, water 1; W2, water 2; PD, Powerade; SS, Sustagen Sport.

7

8 **Figure 2.** Net body mass change following exercise-induced fluid loss and subsequent
9 consumption of food and different beverages ($n=10$). W1, water 1; W2, water 2; PD,
10 Powerade; SS, Sustagen Sport. * Significant difference compared to previous measures. Pre-
11 ex, pre-exercise. Post-ex, post-exercise. Values are mean \pm SD.

12

13 **Figure 3.** Mean reaction time performance on the CRT task ($n=10$). * Significant difference
14 compared to Pre-Ex measures. Pre-Ex, pre-exercise; Post-Ex, post-exercise (within 15
15 minutes of exercise cessation); H1, end of recovery hour one; H2, end of recovery hour two;
16 H3, end of recovery hour three; H4, end of recovery hour four; W1, water 1; W2, water 2;
17 PD, Powerade; SS, Sustagen Sport. Values are mean \pm SEM.

18

19 **Figure 4.** Mean proportion (%) of correct responses on the CRT task ($n=10$). Pre-Ex, pre-
20 exercise; Post-Ex, post-exercise (within 15 minutes of exercise cessation); H1, end of
21 recovery hour one; H2, end of recovery hour two; H3, end of recovery hour three; H4, end of
22 recovery hour four; W1, water 1; W2, water 2; PD, Powerade; SS, Sustagen Sport. Values are
23 mean \pm SEM.

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