



Citation for published version:

Peacock, OJ, Thompson, D & Stokes, KA 2012, 'Voluntary drinking behaviour, fluid balance and psychological affect when ingesting water or a carbohydrate-electrolyte solution during exercise', *Appetite*, vol. 58, no. 1, pp. 56-63. <https://doi.org/10.1016/j.appet.2011.08.023>

DOI:

[10.1016/j.appet.2011.08.023](https://doi.org/10.1016/j.appet.2011.08.023)

Publication date:

2012

Document Version

Peer reviewed version

[Link to publication](#)

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**Voluntary drinking behaviour, fluid balance and psychological affect when
ingesting water or a carbohydrate-electrolyte solution during exercise.**

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ABSTRACT

This study investigated the effects of drink composition on voluntary intake, hydration status, selected physiological responses and affective states during simulated gymnasium-based exercise. In a randomised counterbalanced design, twelve physically active adults performed three 20-min intervals of cardiovascular exercise at 75% heart rate maximum, one 20-min period of resistance exercise and 20 min of recovery with *ad libitum* access to water (W), a carbohydrate-electrolyte solution (CES) or with no access to fluids (NF). Fluid intake was greater with CES than W (1706 ± 157 vs. 1171 ± 152 mL; $P < 0.01$) and more adequate hydration was achieved in CES trials (NF vs. W vs. CES: -1668 ± 73 vs. -700 ± 99 vs. -273 ± 78 g; $P < 0.01$). Plasma glucose concentrations were highest with CES (CES vs. NF vs. W: 4.26 ± 0.12 vs. 4.06 ± 0.08 vs. 3.97 ± 0.10 mmol/L; $P < 0.05$). Pleasure ratings were better maintained with *ad libitum* intake of CES (CES vs. NF vs. W: 2.72 ± 0.23 vs. 1.09 ± 0.20 vs. 1.74 ± 0.33 ; $P < 0.01$). Under conditions of voluntary drinking, CES resulted in more adequate hydration and a better maintenance of affective states than W or NF during gymnasium-based exercise.

Key words: voluntary drinking, hydration, carbohydrate, exercise, core temperature, affective states, behaviour.

INTRODUCTION

Participation in regular physical activity and exercise is associated with numerous health benefits (Blair & Brodney, 1999; Hardman & Stensel, 2008), but of those individuals who begin an exercise programme there is an estimated forty-five percent dropout (Marcus et al., 2006). Although numerous factors are known to determine adherence to an exercise programme (Biddle & Mutrie, 2007), one aspect of exercise with motivational relevance is the affective psychological response (e.g. any pleasant or unpleasant state) that individuals experience during exercise (Ekkekakis, Parfitt, & Petruzzello, 2011). Preliminary data provides direct evidence that a pleasurable affective response to exercise and the associated positive memory of that experience, may increase the likelihood of subsequent long-term adherence to structured exercise (Kwan & Bryan, 2010; Schneider, Dunn, & Cooper, 2009; Williams et al., 2008).

It has been proposed that a causal chain exists linking physiological strain and affective psychological responses to exercise adherence (Lind, Welch, & Ekkekakis, 2009). Hydration status has been largely ignored as a potential mediating factor in this cascade of events towards non-compliance and drop-out from exercise. This is surprising given the well-known negative consequences of hypohydration on cardiovascular and thermoregulatory function during exercise (Montain & Coyle, 1992; Sawka, Young, Francesconi, Muza, & Pandolf, 1985) and emerging evidence that a fluid deficit incurred prior to (Peacock, Stokes, & Thompson, 2011) or during exercise (Backhouse, Biddle, & Williams, 2007) corresponds with impaired affective states. Fluid intake to maintain adequate hydration can minimise these adverse effects, but acute mild and moderate hypohydration appears common in physically active adults performing free-living exercise at fitness centres with unlimited access to water (Peacock et al., 2011).

Several studies indicate that the addition of carbohydrate, sodium and flavouring to plain water stimulates greater voluntary fluid intake and more adequate hydration in exercising populations (Baker, Munce, & Kenney, 2005; Passe, Horn, Stofan, & Murray, 2004; Wilk, Rivera-Brown, & Bar-Or, 2007). Traditionally, nutritional supplementation studies have focussed on “what” the individual is feeling during exercise in terms of the strain of physical work, using subjective ratings of perceived exertion (Borg, 1973). This is conceptually distinct from measuring “how” people feel with reference to the affective response of pleasure-displeasure. The few studies that have examined the impact of nutritional manipulations on basic affect, using the Feeling Scale (Hardy and Rejeski, 1989), have reported that individuals “feel better” with ingestion of water (Backhouse et al., 2007) or a carbohydrate-electrolyte drink during exercise (Backhouse, Bishop, Biddle, & Williams, 2005; Rollo, Williams, Gant, & Nute, 2008). These states are highly relevant as they may play an important role in determining task persistence and the amount of effort that individuals commit to an exercise session (Acevedo, Gill, Goldfarb, & Boyer, 1996).

The effectiveness of carbohydrate-electrolyte drinks in promoting fluid balance and more favourable affective responses (under conditions of voluntary fluid intake) has not been examined in recreationally active adults who participate in gymnasium-based exercise for health and fitness. This is surprising given that so many people (approximately 7 million people in the UK) are reported to exercise in this context (Fitness Industry Association, 2010) and given the potential implications for encouraging positive exercise behaviours. The purpose of this study was to examine the effects of *ad libitum* ingestion of a carbohydrate-electrolyte solution on fluid balance,

physiological function and affective psychological responses to a simulated gymnasium-based exercise session in physically active adults. It was hypothesised that voluntary fluid intake would be higher, and the hypohydration level would be lower, with provision of the carbohydrate-electrolyte drink compared to water or no fluid ingestion, and that the deterioration in physiological function and psychological states would be associated with the overall level of hypohydration.

METHODS

Participants

Twelve recreationally active men (age, 26 ± 5 years; body mass, 78.8 ± 9.3 kg; body fat $16.8 \pm 3.2\%$; $\text{VO}_{2\text{max}}$ 54.9 ± 5.9 mL·kg⁻¹·min⁻¹; HR_{max} 195 ± 7 b·min⁻¹) provided written informed consent before participating in the study. Ethical approval was granted by the local National Health Service Research Ethics Committee. All participants were familiar with gymnasium-based exercise and reported completing 1-5 structured exercise sessions per week of at least 30 min in duration.

Preliminary Measurements

Participants visited the laboratory to complete two preparatory sessions. During the first visit, each participant's one-repetition maximum for chest and leg press resistance exercises was established using a resistance training machine (Concept 2 Inc., USA). The force equivalent to 75% of one-repetition maximum was then calculated and used as the target force during the resistance exercise component of experimental trials. Thereafter, maximal oxygen uptake was determined using a continuous incremental exercise test to volitional exhaustion on a motorised treadmill. Participants ran at a constant speed against an initial gradient of 3%, which was increased by 3% every 3 min until the point of volitional fatigue. One-minute expired air samples, ratings of perceived exertion and heart rates were measured in the final minute of each stage.

During a second visit to the laboratory a tasting session was conducted to determine drink flavour preferences. Two different flavour carbohydrate-electrolyte drinks were provided to each participant in a randomised sequence. Fifty millilitres of fluid chilled to approximately 12°C was served in 150 mL plastic disposable cups. Between

samples, there was a 2-3 min interval while participants cleansed their mouth with water to clear their palate. Immediately after each drink was sampled, participants rated overall drink acceptance, using a modified version of the general labelled magnitude scale (Bartoshuk et al., 2004). The most preferred flavour CES for each individual was used during subsequent experimental trials. Thereafter, participants were fully familiarised with the experimental protocol and performed three 20-min bouts of exercise on a treadmill (Woodway, UK), cross-trainer (Technogym, UK) and cycle ergometer (SRM, Germany), respectively. During these exercise periods, the work rate equivalent to a target exercise heart rate of between 70 to 80% heart rate maximum was established for each exercise apparatus and applied for all experimental trials.

Experimental Design

Participants performed three main trials in a randomized, counterbalanced order and separated by 5-10 days. Previous data describing the typical gymnasium-based exercise habits of recreationally active adults was used to inform the exercise protocol in the present study (Peacock et al., 2011), with particular reference to the mode, duration and intensity of exercise performed. In this study, cardiovascular exercise intensity was described as a percentage of heart rate maximum, and showed that adults typically self-selected an intensity of approximately 75% of heart rate maximum. Given the ecological validity of these data to adults performing gymnasium-based exercise, the work rate equivalent to this target exercise heart rate was established and set for each cardiovascular exercise mode and applied across all experimental treatments. During exercise and in recovery, participants either had *ad libitum* access to water (W), their most preferred flavour 2% carbohydrate-electrolyte solution (CES), or had no access to fluids (NF). Participants were not informed of the potential role of the different

exercise conditions on psychological outcomes in an effort to reduce any expectancy effects. Moreover, each individual participant was tested alone and every effort was made to standardise any interaction between the participant and experimenter.

Pre-trial Standardisation

Experimental sessions were conducted in the afternoon and at the same time of day for each participant. A 2-day dietary record was completed over the 48 h period prior to trial 1, and was then replicated before all other trials (2584 ± 615 kcal·day⁻¹, $45 \pm 4\%$ carbohydrate, $37 \pm 5\%$ fat, $18 \pm 5\%$ protein, 2549 ± 599 mL·day⁻¹ fluid). Participants reported to the laboratory after having fasted for at least 4 hours to minimise the effect of a previous meal on gastric emptying and exercise metabolism. To standardise hydration status and increase the likelihood of euhydration before each exercise trial, participants were instructed to drink 500 mL of water on waking and a further 500 mL 2 h prior to arriving at the laboratory.

Experimental Protocol

Each participant arrived in the laboratory having swallowed an ingestible temperature sensor capsule 6-8 h prior to the beginning of testing for the measurement of intestinal temperature. Participants were then seated in an upright position for a period of 15 min before a pre-exercise blood sample and a 5-min expired gas sample were obtained. After participants had provided a urine sample and emptied their bladder, nude body mass was recorded. Participants were then instrumented with a chest strap and heart rate monitor, before changing into shorts, t-shirt and training shoes. The exercise protocol commenced with a 5-min warm-up on a treadmill at a work rate of between 60 and 70% heart rate maximum. Three 20-min cardiovascular exercise intervals were

then performed on a treadmill, cross-trainer and a cycle ergometer at a predetermined work rate equivalent to approximately 75% of heart rate maximum, and separated by 5-min rest intervals. Participants then completed 4 sets of 10 repetitions at 75% of one repetition maximum, for chest and leg press resistance exercises and with a work to rest ratio of 60 to 90 s. This was followed by 20 min of seated recovery.

Throughout W and CES trials, fluids were permitted *ad libitum* during exercise, in designated rest intervals and in recovery. Heart rate and intestinal temperature were recorded continuously throughout the experimental protocol. Expired gas samples were taken for 1-min during the mid-point of cardiovascular exercise intervals, during the entire work and rest period of resistance exercise sets 3 and 7, and for a 3-min period during the mid-point of recovery. Drink bottle mass, ratings of perceived exertion and psychological affect were recorded at the mid-point of all exercise intervals and immediately following cardiovascular and resistance exercise and after recovery. Blood samples were taken post cardiovascular and resistance exercise and recovery; which was followed by a recording of nude body mass once participants had removed all excess moisture from the skin using a towel, and after all urine output had been collected. Ambient temperature and humidity were recorded at 60-min intervals throughout all testing periods and were not different between treatments; average values recorded were $19.6 \pm 0.9^{\circ}\text{C}$ and $66.5 \pm 7.0\%$ (mean \pm SD), respectively.

Solution Composition and *Ad Libitum* Fluid Intake

Participants had access to filtered tap water or one of two flavours of a commercially available drink (Lucozade Sport Lite, Brentford, England) containing carbohydrate (approximately 2%) and sodium (35 mg per 100 mL). All drinks were served in 750

mL opaque plastic bottles at a temperature of $\sim 12^{\circ}\text{C}$, with the instruction: “this is your drink; more fluid is available if required.” To reduce potential bias, limited explanations were provided to participants regarding differences between test drinks and the specific goal of the study, whilst fluid intake was not encouraged or discouraged throughout testing. A new drink bottle was provided once the fluid bottle content was less than 100 mL, or if requested by a participant.

General Measurements

Fluid intake and urinary losses were measured by weighing drinks bottles and urine collection containers respectively using a digital balance scale, which was accurate to 0.001 kg (Salter 3001, UK). Body mass was measured using a digital balance scale, which was accurate to 0.05 kg (Avery Ltd., UK). Heart rate was monitored throughout trials by telemetry using a Polar S610 HR monitor (Polar Electro Oy, Finland). Intestinal temperature was measured using disposable temperature sensor capsules (Cor-100, HQinc, USA). Environmental temperature and humidity were measured using a wet bulb globe temperature monitor (Quest Temp 36, UK).

Expired Gas Collection and Analysis

Expired gas samples were collected using the Douglas bag method and substrate oxidation was subsequently determined by indirect calorimetry. During resistance exercise intervals, expired air samples were taken during the entire final work: rest set for both chest and leg press exercise. In terms of estimating energy expenditure, the nature of resistance exercise (as an intermittent, high intensity activity of short-duration) violates the normal assumptions of indirect calorimetry, since the respiratory exchange ratio is typically greater than or equal to 1.0. Energy expenditure during resistance

exercise was calculated as being 5.047 kcal (21.1 kJ) per litre of oxygen (Burns, Broom, Miyashita, Ueda, & Stensel, 2006).

Estimated Sweat Loss, Fluid Balance and Urine Analysis

Sweat loss was estimated from the net change in body mass after correction for the mass of fluid consumed and for any urinary losses. No correction was made for the relatively small change in mass loss due to substrate oxidation and evaporative water loss from the lungs. Fluid loss was divided by the duration of the exercise session to obtain sweat rate, while fluid balance was calculated by subtracting sweat loss from total fluid consumed. Hypohydration was calculated using the change in body mass from pre- to post-exercise expressed as a percentage of pre-exercise body mass. Urine samples were immediately analysed in duplicate for osmolality via freezing point depression (Advanced Instruments Inc., USA).

Measures of Psychological Affect and Perceived Exertion

Participants' affective psychological responses were assessed using the Feeling Scale (Hardy & Rejeski, 1989), which provides a measure of the affective dimension of pleasure-displeasure. The Feeling Scale is an 11-point bipolar scale anchored from very good (+5) through neutral (0) to very bad (-5). Participants were asked to rate how they felt at that particular moment. Instructions to participants were: "While participating in exercise it is quite common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasurable. Additionally, feelings may fluctuate across time. That is, one might feel good and bad a number of times during exercise. Scientists have developed a scale to measure such responses. Please select the number on the scale that represents how you feel at this particular moment."

This scale has been used as a measure of psychological affect in a number of physical activity studies (Ekkekakis, 2003) and has been shown to be related to other measures of affective valence (Hall, Ekkekakis, & Petruzzello, 2002), as well as past and present physical activity participation (Hardy & Rejeski, 1989).

Ratings of perceived exertion were assessed using the Borg Scale (Borg, 1973). The scale ranges from 6 to 20, with anchors ranging from “very, very light” to “very, very hard”. Instructions to participants were: “During the exercise session we want you to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Don’t concern yourself with any one factor, such as leg pain, shortness of breath or exercise intensity, but try to focus on your total feeling of exertion. Please select the number on the scale that represents your level of exertion at this particular moment; be as accurate as you can”. Participants were fully familiarised with both scales during preliminary sessions and the order of administration was always the Rating of Perceived Exertion Scale followed by the Feeling Scale.

Blood Sampling and Analysis

Blood samples were drawn by venepuncture from an antecubital vein and dispensed into collection tubes (Microvette 500, Sarstedt, Germany) containing the anti-coagulant ethylenediaminetetraacetic acid; from which duplicate 25 μ L samples were taken for the immediate determination of blood glucose and lactate concentrations using an automated analyser (YSI 2300 Stat Plus, YSI, Ohio, USA). The coefficient of variation for 20 replicates for blood lactate and glucose was 2.2 and 1.5%, respectively.

Statistical Analysis

Sample size estimations were derived from previous data (Peacock et al., 2011) showing that recreationally active adults would have needed to consume an additional mean fluid intake of 506 mL to offset sweat losses incurred during a freely-chosen gymnasium-based exercise session in temperate ambient conditions. Specifically, it was calculated that a sample size of 12 would have an 80% power to detect a difference in mean fluid intake of 506 mL, using a paired t-test with an alpha level of $P < 0.05$. A two-way general linear model for repeated measures (treatment x time) was used to identify overall differences between experimental conditions. The Greenhouse–Geisser correction was used for epsilon < 0.75 , while the Huynh–Feldt correction was adopted for less severe asphericity. Where significant F values were found, the Holm–Bonferroni stepwise correction was applied to determine the location of variance (Atkinson, 2001). Unless otherwise stated, all data are expressed as means \pm standard error of the mean (SEM). Statistical significance was set at the 0.05 level.

RESULTS

Baseline Hydration Status

Body mass was not significantly different between the euhydrated baseline determined from three consecutive morning nude body mass measurements and the baseline body mass preceding each trial (euhydrated baseline= 78.8 ± 2.7 , NF= 78.8 ± 2.5 , W= 78.9 ± 2.6 , CES= 78.9 ± 2.6 kg). Comparable hydration status prior to testing was also indicated by similar pre-trial values for urine osmolality (NF= 283 ± 60 , W= 269 ± 41 , CES= 274 ± 64 mOsmol \cdot kg $^{-1}$).

Fluid Intake

Immediately on commencement of the exercise session, participants voluntarily consumed a greater volume of CES than W, with treatment differences being significant after just 20 min of exercise (210 ± 34 versus 124 ± 32 mL, respectively; $P=0.01$). Increased CES consumption relative to W was maintained during subsequent measurement intervals (treatment: $F_{1,11}=31.6$, $P<0.001$), such that there was a progressive divergence between treatments in the cumulative volume consumed (treatment x time: $F_{7,77}=18.0$, $P<0.001$; Figure 1). The difference in cumulative fluid intake was higher at all time-points throughout CES trials than W trials ($P\leq 0.01$), with the greatest difference apparent by the end of the final measurement interval (1706 ± 157 versus 1171 ± 152 mL, respectively; $P=0.001$).

Estimated Sweat Loss, Urine Output and Net Fluid Balance

There were no significant difference between trials in estimated fluid losses through sweat (NF= 1371 ± 61 , W= 1426 ± 89 , CES= 1415 ± 80 mL) or for total urine production (NF= 217 ± 48 , W= 355 ± 74 , CES= 445 ± 91 mL). A body mass loss was apparent

following cardiovascular exercise under all three treatments (time: $F_{2,15}=143.0$, $P<0.001$; Figure 2). However, the magnitude of this fluid deficit was more pronounced in NF trials (-1668 ± 73 mL) than in W (-700 ± 100 mL) and CES trials (-273 ± 78 mL), with significant differences observed between treatments post exercise and recovery (treatment x time: $F_{2,19}=41.8$, $P<0.001$). This was equivalent to a greater level of dehydration with NF ($-2.13 \pm 0.09\%$) than either fluid trial (treatment: $F_{2,20}=50.6$, $P<0.001$), whereby hydration status was better maintained in CES trials ($-0.34 \pm 0.10\%$) than in W trials ($-0.91 \pm 0.14\%$) throughout the protocol (treatment x time: $F_{2,20}=42.0$, $P<0.001$).

Blood Measurements

Blood glucose concentrations were higher with CES (4.26 ± 0.12 mmol·L⁻¹) than NF (4.06 ± 0.08 mmol·L⁻¹) or W (3.97 ± 0.10 mmol·L⁻¹) trials independent of time (treatment: $F_{2,20}=12.8$, $P<0.001$). No differences in blood glucose concentrations were observed between W and NF trials. Blood lactate concentrations were similar in all trials at baseline (~ 0.5 mmol·L⁻¹). Concentrations peaked immediately post-cardiovascular exercise in all trials (at ~ 1.8 mmol·L⁻¹) and gradually decreased to baseline values by the end of the experimental protocol, independent of treatment (time: $F_{1,14}=20.0$, $P<0.001$).

Intestinal Temperature, Heart Rate and Oxygen Uptake

From pre-exercise levels of approximately 37.1°C, intestinal temperature increased rapidly during the first 20 min and peaked at approximately 38.3°C in all trials. There was a significant effect of time for intestinal temperature (time: $F_{4,40}=85.5$, $P<0.001$), but there were no differences between treatments at any measurement interval (Table 1).

Mean heart rate during cardiovascular and resistance exercise intervals and throughout recovery was greater in NF trials (129 ± 2 beats·min⁻¹) than W and CES (both 124 ± 4 beats·min⁻¹) trials (treatment: $F_{2,20}=3.8$, $P=0.040$), with significant differences observed throughout cycling, resistance exercise and recovery intervals (treatment x time interaction: $F_{5,46}=45.0$, $P=0.002$; Table 1). No differences in heart rate were found between CES and W trials. The results for oxygen uptake were not significantly different between trials (Table 1).

Psychological Affect and Ratings of Perceived Exertion

Subjective ratings of pleasure-displeasure decreased from the onset of exercise in W and NF trials but remained consistent with baseline ratings in CES trials, with statistically significant differences during the final cardiovascular exercise bout ($P \leq 0.04$; Figure 3). A sharp increase in ratings of pleasure-displeasure was observed post-cardiovascular exercise, which decreased by the mid-point of resistance exercise, before a further transient increase was observed under all treatments. A subsequent increase in ratings of pleasure-displeasure was then observed in CES trials, while ratings in W and NF trials followed the opposite pattern. The magnitude of these responses revealed significantly greater ratings of pleasure-displeasure in CES trials than W (effect size = 1.0) and NF (effect size = 1.6) trials (treatment: $F_{2,20}=16.9$, $P < 0.001$). The difference in ratings of pleasure-displeasure were greater with CES than NF from 65 min onwards, and were significantly more positive than W at 65, 75, and 140 min (treatment x time: $F_{9,88}=2.3$, $P=0.026$).

Ratings of perceived exertion increased throughout cardiovascular exercise and were maintained above baseline values during resistance exercise under all treatments (time:

$F_{2,18}=5.9, P=0.012$). Ratings of perceived exertion were significantly higher with NF (13.1 ± 0.4) trials than CES (12.3 ± 0.5) trials (treatment: $F_{2,20}=6.8, P=0.006$) but were not different to W (12.8 ± 0.4) trials. No differences in ratings of perceived exertion were found between fluid trials.

DISCUSSION

The results of this study suggest that, in situations of *ad libitum* fluid intake during gymnasium-based recreational exercise in physically active adults, a flavoured carbohydrate-electrolyte solution (CES) was consumed in greater quantities and was more effective in maintaining fluid balance than water (W). In contrast to our original hypothesis, there was no difference in measures of cardiovascular or thermal strain between fluid trials despite a greater level of hypohydration with W than CES. Of particular note, ratings of pleasure-displeasure (i.e. psychological affect) were better maintained with voluntary intake of CES than W. This suggests a beneficial role for the provision of CES, beyond the oft-cited physiological benefits, that may ultimately impact upon task persistence and adherence to a physically active lifestyle.

A greater volume of CES than W was consumed from the onset of exercise and during each discrete measurement interval throughout the experimental protocol. Since body fluid losses through sweat and urine were similar between sessions, the disparity in net fluid balance between trials directly reflects differences in fluid intake. Although voluntary intake was sufficient to prevent hypohydration of more than 1% of initial body mass in both fluid sessions, the greater total volume of fluid consumed with CES (1706 ± 157 mL) than W (1171 ± 152 mL) elicited more adequate hydration at the end of CES trials ($-0.34 \pm 0.10\%$) than W trials ($-0.91 \pm 0.14\%$). These data are consistent with the findings of previous studies into the efficacy of carbohydrate-electrolyte drinks in a variety of populations and exercise conditions (Baker et al., 2005; Bergeron, Waller, & Marinik, 2006; Clapp, Bishop, Smith, & Mansfield, 2000; Clapp, Bishop, & Walker, 1999; Passe et al., 2004; Rivera-Brown, Gutierrez, Gutierrez, Frontera, & Bar-Or, 1999; Wilk & BarOr, 1996; Wilk et al., 2007). However, the present results provide

a unique insight specific to physically active adults performing a simulated “typical” gymnasium-based exercise session (Peacock et al., 2011). Although the current investigation was not designed to uncover the mechanisms by which CES increased voluntary fluid intake, it has been suggested that this could be a result of a behavioural (e.g. drink palatability) mechanism and/or enhanced thirst stimulation through a physiological (e.g. osmotic due to drink sodium content) mechanism (Wilk & BarOr, 1996; Wilk et al., 2007). Further research is required to explore the relative impact of test drinks and experimental conditions of the present study on these homeostatic and hedonic reward systems.

Hypohydration in exercise has been shown to impair cardiovascular and thermoregulatory function, whereby the magnitude of these effects is relative to the overall fluid deficit (Montain & Coyle, 1992; Sawka et al., 1985). It is unsurprising, therefore, that the additional body mass loss incurred with no fluid ingestion was associated with elevated heart rates and ratings of perceived exertion in comparison to fluid trials. However, it is of note that intestinal temperature was similar between all experimental conditions, irrespective of the lower level of hypohydration reported with *ad libitum* access to fluids. Despite more adequate hydration with CES, ratings of perceived exertion, blood lactate levels and heart rates were not significantly different to those reported in W trials. Thus, a further valuable insight to be derived from these data is that drinking of plain water in sufficient quantities may be adequate to minimise potential negative physiological disturbances in situations of mild hypohydration during recreational exercise. Conversely, the finding that blood glucose concentrations were better maintained with CES may allow for an improved exercise capacity given that

carbohydrate depletion may contribute towards causing fatigue during any exercise task lasting longer than approximately 30-40 minutes (Shirreffs, 2009).

One particularly notable outcome difference between trials was the disparity in affective psychological responses. Ratings of pleasure-displeasure decreased markedly throughout cardiovascular exercise with W and NF, but were maintained at or above pre-exercise values with CES. Thereafter, a temporary improvement in affective ratings was observed during the subsequent rest period in all trials. This is consistent with the 'rebound' in psychological ratings typically reported to occur in recovery after cardiovascular exercise (Backhouse et al., 2007; Backhouse et al., 2005), although the disparity in ratings of pleasure-displeasure was maintained between trials following resistance exercise and further recovery. These data are comparable with previous literature investigating the impact of W (Backhouse et al., 2007) or CES (Backhouse et al., 2005; Rollo, Cole, Miller, & Williams, 2010) relative to no fluid ingestion on affective responses in endurance trained males during exercise.

It has been postulated that differences in affective states may reflect an attenuation of the rise in core temperature associated with fluid ingestion during exercise (Backhouse et al., 2007). However, differences in cardiovascular and thermoregulatory responses between trials appear to be insufficient to explain these findings in the current investigation. Since low blood glucose concentrations have been associated with negative affective changes (Gold, Macleod, Frier, & Deary, 1995), differences in rated pleasure-displeasure between trials may reflect the finding that plasma glucose concentrations were better preserved with CES than W or NF. As an alternative or synergistic explanation, neuroimaging data have shown a positive central effect on

hedonic reward process in the brain in response to mouth rinsing with water (de Araujo, Kringelbach, Rolls, & McGlone, 2003) or carbohydrate (Chambers, Bridge, & Jones, 2009) that may generate a “feel good” effect during exercise.

Speculation exists that a positive affective response to exercise will elicit greater enjoyment of the exercise session, result in a lasting positive memory of the exercise experience, and is likely to predict continuation of a physically active lifestyle (Ekkekakis, Hall, & Petruzzello, 2004; Parfitt, Rose, & Burgess, 2006; Williams et al., 2008). Indeed, there is preliminary evidence that more pleasurable responses to exercise are associated with an increase in the amount of time individuals allocate to daily moderate-to-vigorous physical activity and exercise (Kwan & Bryan, 2010; Schneider et al., 2009; Williams et al., 2008). The finding reported here that recreational exercisers “felt better” with *ad libitum* access to CES provides an important basis for further examination of the impact of nutritional manipulations upon exercise tolerance (e.g. self-selected exercise intensity) and long-term adherence.

For those aiming to achieve energy balance or weight loss, it may appear somewhat counterintuitive to ingest a carbohydrate-based drink during exercise. In the present study, the mean \pm standard deviation acute energy deficit associated with the exercise session was 916 ± 91 kcal. This deficit was modestly reduced by the consumption of 171 ± 54 kcal of carbohydrate with ingestion of the low-energy CES (i.e. 2% carbohydrate). Whilst this might modestly reduce the net deficit from each exercise bout, this has to be viewed alongside the potential for greater overall energy expenditure through exercise (e.g. due to an increase in self-selected exercise intensity, duration and/or frequency), better long term adherence or if this is counterbalanced by a reduction in energy intake

during subsequent meals (Melby et al., 2002). A different experimental design to that used in the present study would be required to consider the potential interaction between drink composition, tolerance of exercise, and energy balance.

A limitation of the present study was that it was not possible to undertake a double-blind investigation, and participants may have perceived they were receiving a beneficial treatment (in one of more of the conditions); thus potentially influencing subjective responses. However, expectancy effects were likely minimised because participants were not made aware of the potential role of the intervention on psychological outcomes, while the lack of differences in the more commonly reported perceived exertion ratings further supports the validity of the findings. A further limitation of the present study was that, although participants were all physically active, they undoubtedly varied in terms of overall fitness and level of conditioning. This may have influenced sweat rates, fluid intake and affective responses to exercise, but serves to increase the generalisability of our findings. Nonetheless, these data may be unique to populations that engage in gymnasium-based exercise and future research should be performed in alternative physical activity environments (e.g. walking outdoors).

In conclusion, the results of the present study showed that a flavoured carbohydrate-electrolyte drink promoted greater voluntary intake and more adequate hydration than water in physically active adults performing a simulated recreational exercise session. In addition, subjective ratings of psychological affect were better maintained during exercise with the carbohydrate-electrolyte drink than either water or no fluid provision, which has potential implications related to task persistence, and may ultimately play an important role in future exercise participation.

Acknowledgements

This study received financial support from GlaxoSmithKline.

FIGURE CAPTIONS

Figure 1 The cumulative volume of carbohydrate-electrolyte solution (CES) or water (W) consumed throughout the protocol. ^a $P \leq 0.01$ between CES and W trials.

Figure 2 Whole body net fluid balance throughout the protocol with *ad libitum* access to water (W), carbohydrate-electrolyte solution (CES), or with no fluid (NF). ^b $P \leq 0.01$ between all trials.

Figure 3 Ratings of pleasure-displeasure throughout the protocol with *ad libitum* access to water (W), carbohydrate-electrolyte solution (CES), or with no fluid (NF). ^a $P \leq 0.05$ between CES and W trials. ^d $P \leq 0.05$ between NF and CES trials.

Table 1 Core temperature, heart rate and oxygen uptake at baseline and during each exercise interval and in recovery with no fluid (NF), water (W) or the carbohydrate-electrolyte solution (CES). ^cP≤0.05 between NF and fluid trials.

	Baseline	Run	Cross-train	Cycle	Resistance	Recovery
Intestinal Temperature (°C)						
NF	37.21 ± 0.07	37.83 ± 0.05	38.17 ± 0.06	38.21 ± 0.07	37.76 ± 0.05	37.49 ± 0.06
W	37.27 ± 0.09	37.82 ± 0.04	38.18 ± 0.07	38.20 ± 0.09	37.67 ± 0.05	37.41 ± 0.06
CES	37.30 ± 0.08	37.88 ± 0.06	38.21 ± 0.07	38.20 ± 0.10	37.73 ± 0.07	37.42 ± 0.06
Heart Rate (beats·min ⁻¹)						
NF	59 ± 3	151 ± 2	153 ± 3	152 ± 2 ^c	110 ± 3 ^c	79 ± 2 ^c
W	59 ± 3	150 ± 3	148 ± 4	147 ± 3	104 ± 4	75 ± 3
CES	59 ± 3	150 ± 3	149 ± 4	146 ± 4	103 ± 4	74 ± 4
Oxygen Uptake (L·min ⁻¹)						
NF	0.31 ± 0.01	3.03 ± 0.07	2.75 ± 0.09	2.68 ± 0.08	0.93 ± 0.04	0.35 ± 0.02
W	0.30 ± 0.01	3.00 ± 0.10	2.60 ± 0.10	2.58 ± 0.10	0.90 ± 0.03	0.33 ± 0.01
CES	0.30 ± 0.01	3.03 ± 0.09	2.71 ± 0.10	2.65 ± 0.09	0.92 ± 0.04	0.34 ± 0.01

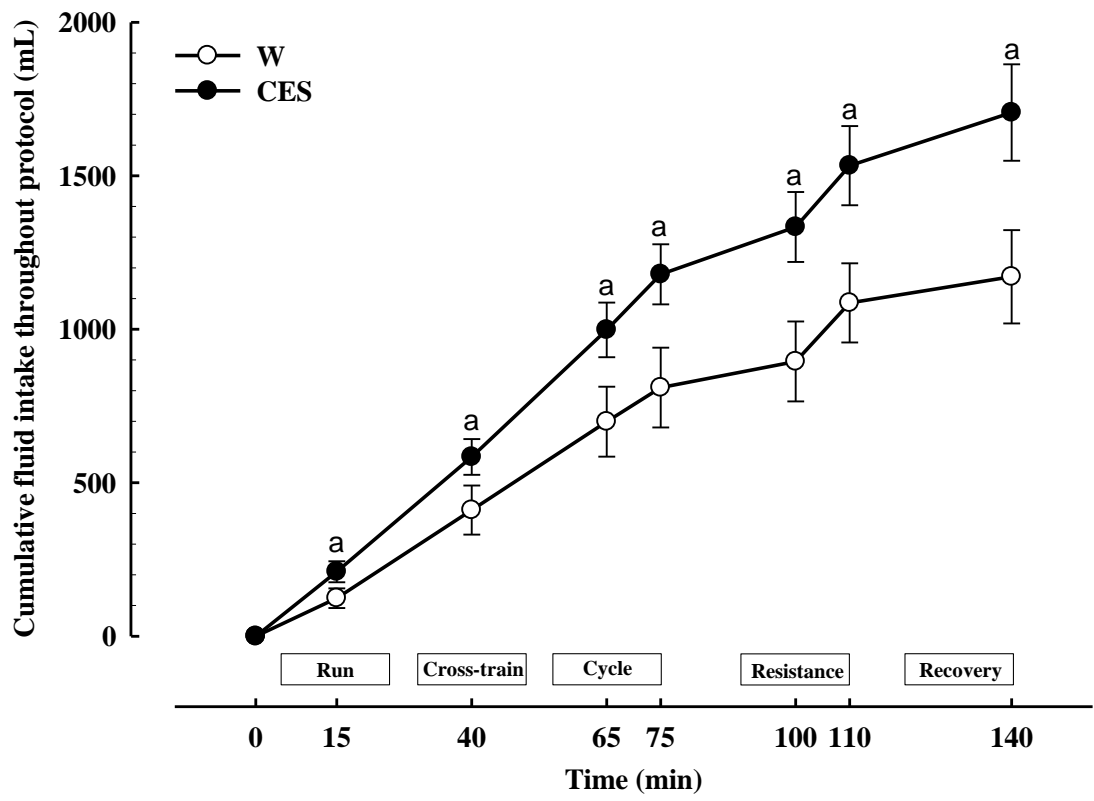


Figure 1

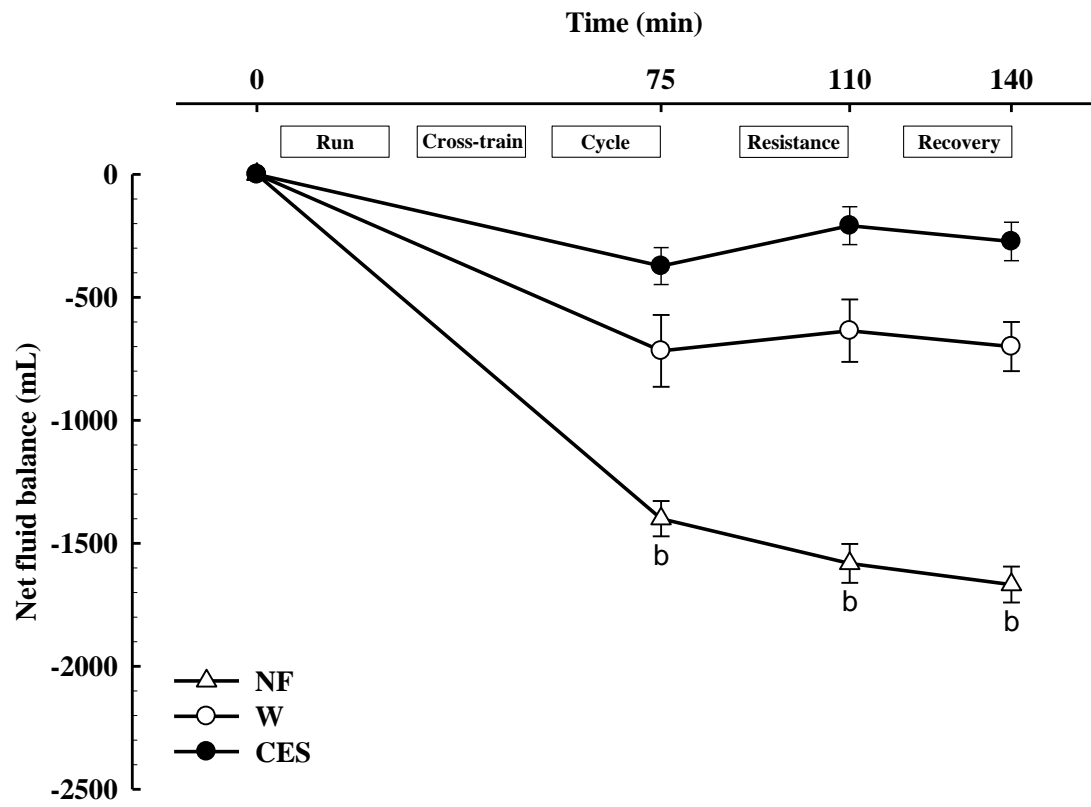


Figure 2

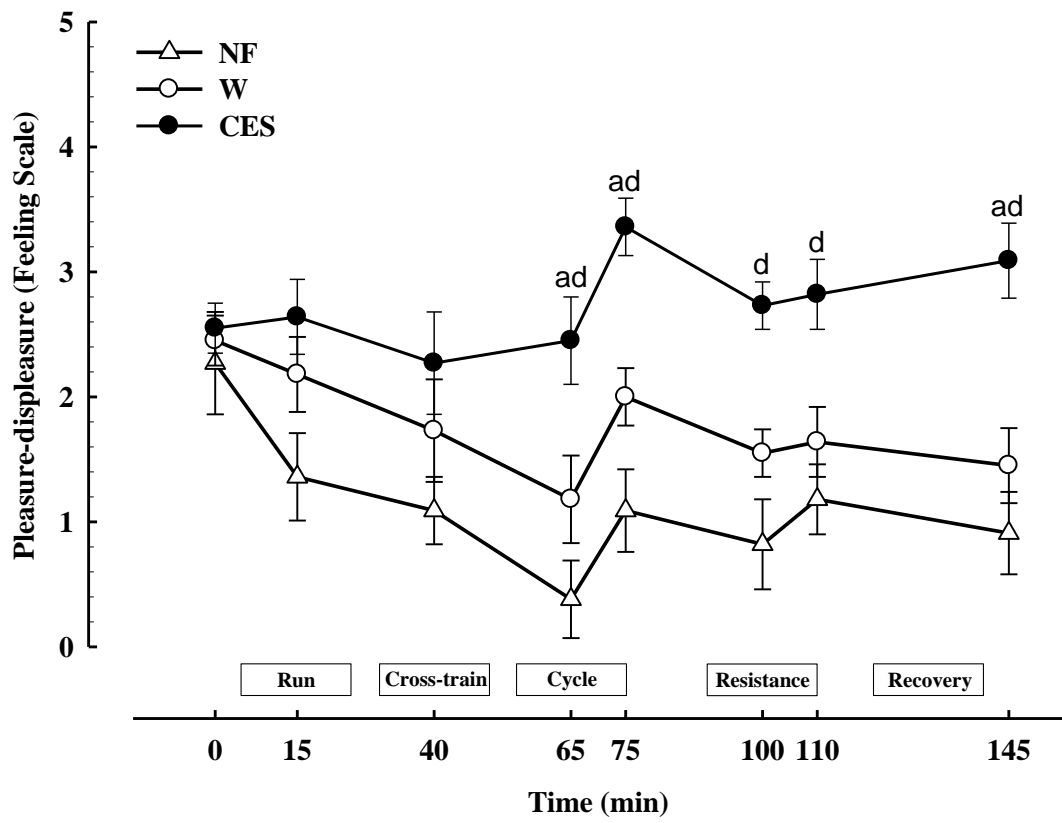


Figure 3

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