University of Wollongong

Research Online

Faculty of Science, Medicine and Health -
Papers: part A

Faculty of Science, Medicine and Health

1-1-2015

The effect of ice-slushy consumption on plasma vasoactive intestinal peptide during prolonged exercise in the heat

Catriona A. Burdon

University of Sydney, cburdon@uow.edu.au

Patricia Ruell

University of Sydney

Nathan A. Johnson

University of Sydney

Phillip G. Chapman

Australian Catholic University

Sinead O'Brien

University of Sydney

See next page for additional authors

Follow this and additional works at: <https://ro.uow.edu.au/smhpapers>

Part of the [Medicine and Health Sciences Commons](#), and the [Social and Behavioral Sciences Commons](#)

Recommended Citation

Burdon, Catriona A.; Ruell, Patricia; Johnson, Nathan A.; Chapman, Phillip G.; O'Brien, Sinead; and O'Connor, Helen T., "The effect of ice-slushy consumption on plasma vasoactive intestinal peptide during prolonged exercise in the heat" (2015). *Faculty of Science, Medicine and Health - Papers: part A*. 3169.
<https://ro.uow.edu.au/smhpapers/3169>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

The effect of ice-slushy consumption on plasma vasoactive intestinal peptide during prolonged exercise in the heat

Abstract

The aim of this study was to determine the effect of exercise in the heat on thermoregulatory responses and plasma vasoactive intestinal peptide concentration (VIP) and whether it is modulated by ice-slushy consumption. Ten male participants cycled at 62% $\dot{V}O_{2\max}$ for 90 min in 32 °C and 40% relative humidity. A thermoneutral (37 °C) or ice-slushy (-1 °C) sports drink was given at 3.5 ml kg⁻¹ body mass every 15 min during exercise. VIP and rectal temperature increased during exercise (mean±standard deviation: 4.6±4.4 pmol L⁻¹, P=0.005; and 1.3±0.4 °C, P<0.001 respectively) and were moderately associated (r=0.35, P=0.008). While rectal temperature and VIP were not different between trials, ice-slushy significantly reduced heat storage (P=0.010) and skin temperature (time×trial interaction P=0.038). It appears that VIP does not provide the signal linking cold beverage ingestion and lower skin temperature in the heat.

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details

Burdon, C. A., Ruell, P., Johnson, N., Chapman, P., O'Brien, S. & O'Connor, H. T. (2015). The effect of ice-slushy consumption on plasma vasoactive intestinal peptide during prolonged exercise in the heat. *Journal of Thermal Biology*, 47 59-62.

Authors

Catriona A. Burdon, Patricia Ruell, Nathan A. Johnson, Phillip G. Chapman, Sinead O'Brien, and Helen T. O'Connor

1 **The effect of ice-slusly consumption on plasma vasoactive intestinal peptide during**
2 **prolonged exercise in the heat**

3

4 Catriona A. Burdon¹, Patricia Ruell¹, Nathan Johnson¹, Phillip Chapman², Sinead
5 O'Brien¹ and Helen T. O'Connor²

6

7 ¹ Exercise, Health and Performance Research Group, Faculty of Health Sciences,
8 University of Sydney, Sydney, Australia; ² Exercise Science, Australian Catholic
9 University, Sydney, Australia

10

11 **Corresponding author:** Patricia Ruell

12 patricia.ruell@sydney.edu.au

13 Discipline of Exercise and Sport Science

14 Faculty of Health Sciences

15 University of Sydney

16 PO Box 170 Lidcombe

17 NSW 1825 Australia

18 Phone: +61293519309

19 Fax: +61 2 93519204

20 Other authors:

21 Catriona Burdon: cburdon@uow.edu.au

22 Nathan Johnson: nathan.johnson@sydney.edu.au

23 Phillip Chapman: phillip.chapman@acu.edu.au

24 Sinead O'Brien: obrien.s91@hotmail.com

25 Helen T. O'Connor: helen.oconnor@sydney.edu.au

26

1 **Abstract**

2 The aim of this study was to determine the effect of exercise in the heat on
3
4 thermoregulatory responses and plasma vasoactive intestinal peptide concentration
5
6 (VIP) and whether it is modulated by ice-slusly consumption. Ten male participants
7
8 cycled at 62 % VO_2max for 90 min in 32 °C and 40 % relative humidity. A thermoneutral
9
10 (37 °C) or ice-slusly (-1 °C) sports drink was given at 3.5 ml·kg⁻¹ body mass every 15 min
11
12 during exercise. VIP and rectal temperature increased during exercise (mean ± standard
13
14 deviation: 4.6± 4.4 pmol·L⁻¹, $P=0.005$; and 1.3 ± 0.4 °C, $P<0.001$ respectively) and were
15
16 moderately associated ($r=0.35$, $P=0.008$). While rectal temperature and VIP were not
17
18 different between trials, ice-slusly significantly reduced heat storage ($P=0.010$) and
19
20 skin temperature (time*trial interaction $p=0.038$). It appears that VIP does not provide
21
22 the signal linking cold beverage ingestion and lower skin temperature in the heat.
23
24
25
26
27

28 **Keywords: beverage temperature, endurance exercise, thermoregulation, cold drink**
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1.1 Introduction

It has been suggested that the temperature of fluids ingested during exercise may influence thermoregulation (Lee and Shirreffs, 2007). The hormone vasoactive intestinal peptide (VIP) is a potent vasodilator (Jenssen et al., 1988) that can alter peripheral blood flow (Said and Mutt, 1970b) and may have a role in circulatory and thermoregulatory adaptations to exercise (Hilsted et al., 1980). The rationale behind the present study was to investigate whether there was a link between changes in plasma VIP and cold beverage ingestion.

It is well documented that endurance exercise in a hot environment increases body core temperature which triggers sweating and an increase in skin blood flow (SBF) which helps to dissipate body heat (Gisolfi and Wenger, 1984). As substantial fluid loss from sweating results in a decrease in plasma volume which may further contribute to the rise in rectal temperature (Tr) (Montain and Coyle, 1992), regular and adequate fluid ingestion is recommended (Sawka et al., 2007). Recently, there has been interest in consumption of cold beverages to enhance thermoregulation and exercise performance in the heat. Cold beverage ingestion has been observed to decrease rectal (Tr) and skin temperature (Tsk) compared to thermoneutral beverages (Armstrong et al., 1985; Lee and Shirreffs, 2007; Lee et al., 2008b; Wimer et al., 1997). The mechanism underpinning the effect of cold beverage ingestion on thermoregulation (Tr, Tsk and heat storage) during prolonged exercise requires further investigation. Specifically, the association between cold beverage consumption and lowered Tsk suggests that a signal may exist between the two factors.

Skin temperature is considered a quasi-index of SBF (Charkoudian, 2003) which increases during exercise in the heat to assist with heat loss via convection, radiation and sweat evaporation (Gisolfi and Wenger, 1984). A reduction in Tsk and/or SBF

1 coupled with a reduction in heart rate (HR) is consistent with a reduction in
2 cardiovascular strain following cold beverage ingestion (Armstrong et al., 1985; Lee and
3 Shirreffs, 2007; Lee et al., 2008b; Wimer et al., 1997). This reduction in Tsk and skin
4 blood flow may be due to a decrease in the circulating hormone VIP. Previous studies
5 have demonstrated that VIP increases with exercise duration (4-20 pmol.L⁻¹) (Galbo et
6 al., 1979; Hilsted et al., 1980; Schaffalitzky de Muckadell et al., 1977) and with passive
7 heat exposure (Jenssen et al., 1988). VIP is known to have receptors in both the skin
8 and gastrointestinal (GI) tract and is a potent vasodilator, including of the skin (Bennett
9 et al., 2003; Said and Mutt, 1970a) and is a candidate for the signal between cold
10 beverage ingestion and decreased Tsk. A possible mechanism is that ingestion of the
11 cold beverage inhibits release of VIP from nerve fibres in the gut into the plasma which
12 leads to lower cutaneous vasodilatation and reduced skin blood flow and skin
13 temperature. Therefore, the aim of this study was to examine the effect of serial
14 consumption of a cold beverage during exercise on VIP and thermoregulatory
15 responses. We hypothesised that during prolonged exercise in the heat, serial
16 consumption of ice-slusky (ICE) would reduce Tsk and VIP compared to a
17 thermoneutral control beverage (CON).

18
19

20 **2.1 Methods**

21 Healthy, male, naturally heat acclimatised, endurance cyclists or triathletes were
22 targeted for recruitment. After completing a medical screening questionnaire,
23 participants gave written informed consent which was obtained according to the
24 Declaration of Helsinki. Ten participants (data given as mean ± standard deviation; age:
25 30.1±7.0 years; height: 175± 6.5 cm; body mass: 75.1±9.4 kg; estimated body fat

12.3±2.7%; $\dot{V}O_2$ max: 61.8± 5.6 ml.kg⁻¹.min⁻¹) completed the study which was approved by the university Human Research Ethics Committee.

2.2 Preliminary measures

At the beginning of the first visit, participants were measured for nude body mass (Mettler ID 1, Albstadt, Germany) and stretch stature to the nearest 0.5cm using a stadiometer (Harpender, United Kingdom). Hydrostatic weighing was used to estimate body composition. Participants wore a nose-clip, expired maximally and were submerged sitting on a chair suspended from a scale (Chatillon, New York). Weight was recorded when participants were motionless under water. Residual volume was estimated (van der Ploeg et al., 2000) by assessing the composition of oxygen and carbon dioxide in rebreathed air (5L pure oxygen). Body density (Goldman and Buskirk, 1961), fat free mass and percent body fat (Siri, 1956) were calculated. Underwater weighing was repeated three times and the result accepted if at least 2 measures were within 1%.

Peak aerobic capacity was measured on a cycle ergometer (Lode Excalibur, Groningen, Netherlands). The test consisted of four sub-maximal steady-state power outputs of five min each (100, 150, 200, 250 W) followed by an incremental increase in power (30 W.min⁻¹) until volitional fatigue. Expired air was collected using a Douglas bag for a minimum of 40 s during each stage and prior to fatigue. Samples were analysed with Servomex Pm1111E and Ir1507 sensors (Servomex, Crowborough, UK) to determine oxygen and carbon dioxide fractions. Gas volume was measured with a dry gas meter (Harvard, UK). Power output and $\dot{V}O_2$ during the sub-maximal exercise was used to calculate workload for the following trials using linear regression.

2.3 Experimental design

Participants attended the laboratory for three sessions: a preliminary (described above) and two experimental trials, ingesting either ice slushy -1 °C (ICE) or thermoneutral 37

1 °C (CON) beverages. The experimental trials were performed in a randomised order
 2 separated by 7-21 days.
 3 During the experimental trials, participants cycled on the ergometer at steady state for
 4 90 min in a climate chamber at 32 °C, 40 % relative humidity (RH) and wind speed set at
 5 3.6 km·h⁻¹. The selected power output based on the previous peak aerobic capacity test
 6 was calculated to elicit 60 % of VO₂peak using self-selected cadence. A commercially
 7 available 7.4 % carbohydrate-electrolyte sports drink (Powerade Isotonic, Coca-Cola
 8 Amatil, Australia) was consumed every 15 min at 3.5 ml per kg body weight in both
 9 trials. The temperature of CON was controlled by a thermostatic water bath (E-5A,
 10 Julabo, Germany) and ICE was made using a commercial 'slush' machine (Iceotonic,
 11 Essential Slush, Australia). Beverage temperature was checked prior to consumption
 12 using an electronic thermometer (Thermistor 400 series, Cole Parmer, Illinois, USA).
 13 Beverage composition and carbohydrate consumption was the same for both trials.
 14 Heart rate (S410, Polar Electro, Kempele, Finland) was taken every minute during SS.
 15 Expired air was collected using a Douglas bag for 1 min at 10, 30, 60 and 90 min. Rectal
 16 temperature was recorded via a custom made rectal probe every minute. Skin
 17 temperature was recorded every minute using four skin thermistors (DS1921H-F5
 18 ibutton, Maxim, USA) placed on the left side (upper chest, mid humerus, mid calf and
 19 mid thigh) and were combined to give an overall temperature: $T_{sk} = 0.3T_{chest} + 0.3T_{arm}$
 20 $+ 0.2T_{thigh} + 0.2T_{leg}$ (Ramanathan, 1964). Whole body skin blood flow was calculated
 21 from Tr and Tsk measurements using the following equation: $\dot{Q}_{sk} = 1/C \times h/(Tr - Tsk)$,
 22 where $\dot{Q}_{sk}$ is skin blood flow, C is specific heat of blood ($\approx 0.87 \text{ kcal} \cdot \text{C}^{-1} \cdot \text{l}^{-1}$) and h is work
 23 measured by VO₂ (L·min⁻¹) (Rowell, 1986). Body heat storage (HS, W·min⁻²) was
 24 estimated as: $(0.8 \cdot \Delta Tr + 0.2 \cdot \Delta Tsk) \cdot c_p$, where c_p is specific heat of body tissue
 25 (Havenith et al., 1995). The specific heat of body tissue was adjusted for percent fat
 26 mass ($3.49 \text{ kJ} \cdot \text{C}^{-1} \cdot \text{kg}^{-1}$; (Aoyagi et al., 1996)).

1 To control for the effect of diet and hydration status, guidelines to consume a
2 minimum of 6g of carbohydrate per kilogram of body-mass were provided to
3 participants and they were instructed to ingest 30 ml per kilogram of body mass. To
4 improve compliance to dietary control, these guidelines were based on food consumed
5 when participants completed a three day food diary prior to commencement of the
6 study. This recommended diet was consumed in the 24 h prior to each visit and
7 confirmed with a 24 h food diary. Dietary intake was analysed using Australian dietary
8 analysis software (FoodWorks Version 7.0.2921, Xyris Pty Ltd). Participants refrained
9 from strenuous activity and alcohol and replicated caffeine consumption for 24 h
10 before fasting for 6 h (except water consumption) prior to presenting to the lab.
11 Participants commenced each trial at the same time each day.

12 *2.4 Blood analysis*

13 *2.4.1 Osmolality*

14 At rest, a cannula was inserted into the antecubital vein. Prior to and post exercise 4 ml
15 blood was collected, left to clot, centrifuged, the serum removed and osmolality
16 determined by a cryoscopic osmometer (Osmomat 030, Gonotec, Berlin, Germany).
17 Euhydration was considered to be a blood osmolality <290 mOsmol/kg.

18 *2.4.2 VIP*

19 At rest, 30 min, 60 min and post exercise, 6mL blood was collected in EDTA tubes
20 containing Trasylol (3,000 KIU in a 6 ml tube) and the tube placed in an ice bath.
21 Following centrifugation at 4 °C the plasma was removed and stored at -85 °C. Samples
22 were analysed for VIP using a commercial RIA kit (EURIA- VIP, Euro Diagnostica, Malmo,
23 Sweden). Tubes were counted using a Wizard 1470 gamma counter (Perkin Elmer, MA,
24 USA). The sensitivity of the VIP assay was 3 pmol·L⁻¹.

25 *2.5 Statistical Analyses*

1 Statistical analysis was performed using SPSS version 19.0 (SPSS Inc., Chicago, IL) with
 2 all outcome variables checked for normality. A two-way repeated-measures ANOVA
 3 was used to evaluate differences between and within trials. To correct for violations of
 4 the assumption of sphericity with the repeated factor, the Huyn-Feldt correction was
 5 applied to the F ratio. Simple contrasts were used to further analyse the time effect
 6 where it was significant. Where a significant interaction effect was found pairwise
 7 differences were identified using the Bonferroni procedure. Pearson's correlation
 8 coefficient were used to determine the association between VIP, Tr and Tsk. Statistical
 9 significance was set at $P < 0.05$. Data are reported as mean $\pm$ standard deviation.

10

11 **3.1 Results**

12 No significant differences were detected in any of the observed variables (Tr, Tsk or
 13 VIP) at baseline and no order effect was found.

14 Participant food diaries confirmed compliance with dietary carbohydrate prescription.

15 Participants consumed 186 ± 36 kJ of total energy per kilogram of body mass, which
 16 equates to roughly 13, 950 kJ. Carbohydrate consumption was 6.9 ± 1.2 g per kilogram
 17 of body mass. There was no difference in total energy or carbohydrate consumption
 18 between trials ($P=0.38$ and $P=0.34$ respectively). Participants arrived hydrated to the
 19 laboratory for all trials with no observed difference between trials for body mass or
 20 serum osmolality (76.5 ± 9.6 kg; 287.5 ± 3.3 mOsmol $\cdot$ kg $^{-1}$, $P=0.99$ for both).

21 While Tr increased over time ($P < 0.001$), no time*trial difference was detected ($P=0.75$)
 22 (Figure 1a). There was no difference in Tr between trials at the end of exercise (overall
 23 mean 38.2 ± 0.4 °C, $P=0.79$) or in absolute change from rest to 90 min (overall mean 1.3
 24 ± 0.4 °C, $P=0.88$).

25 A significant decrease over time in skin temperature was detected (Figure 1b, $P=0.001$)
 26 with ICE tending to be lower vs. CON ($p=0.063$) and a time*trial interaction ($p=0.038$).

1 The decrease in skin temperature from rest to end for ICE(-1.1 ± 0.5 °C) was
 2 significantly different to CON (-0.6 ± 0.7 °C, $P=0.046$). At the completion of exercise Tsk
 3 was lower with ICE (32.9 ± 0.5 °C) vs CON (33.5 ± 0.8 °C) ($P=0.007$).
 4 Heat production was similar between trials (overall mean 396 ± 39 W.min⁻², $P=0.9$).
 5 During the exercise period ICE (14.6 ± 7.8 W.min⁻²) significantly reduced heat storage
 6 versus CON (22.1 ± 5.8 W.min⁻²; $P=0.010$).
 7 Heart rate increased over time during exercise ($P<0.001$) but was not different between
 8 trials ($P=0.09$). Calculated whole body SBF decreased during exercise ($P<0.01$) with no
 9 significant difference between trials detected ($P=0.46$).
 10 VIP (n=7) increased over time (Figure 2, $P=0.005$) in all participants with no significant
 11 difference between trials ($P=0.16$). Post hoc analysis showed that VIP at 30, 60 and 90
 12 min was greater than rest ($p<0.05$). A moderate, positive and significant correlation
 13 was found between VIP and Tr ($r=0.35$, $P=0.008$) and between VIP and Tsk ($r=0.42$,
 14 $P=0.003$) (Figure 3).

16 **4.1 Discussion**

17 Cold beverage ingestion during prolonged exercise in the heat has previously been
 18 shown to improve thermoregulation via a reduction in Tr and particularly Tsk (Wimer et
 19 al., 1997), which suggests a link between the two factors. It was hypothesised that VIP
 20 may explain part of this link. This study found that consumption of ice-slushty reduced
 21 Tsk and heat storage. While we also observed an increase in VIP during exercise in the
 22 heat, regular consumption of ICE did not alter the concentration of circulating VIP. This
 23 lack of effect of beverage temperature on VIP, independent of the effect of
 24 environmental temperature and/or exercise duration (Galbo et al., 1979; Jenssen et al.,
 25 1988; MacLaren et al., 1995) suggests that changes in VIP do not provide the

1 physiological signal for the thermoregulatory effects of cold beverage consumption
2 during exercise.

3

4 The findings of this study are consistent with previous literature where serial cold
5 beverage ingestion during exercise was associated with a reduction in heat storage and
6 Tsk but not Tr (Burdon et al., 2010; Lee et al., 2008a). The reduction in heat storage
7 suggests the formation of a heat sink, which has been hypothesised to absorb some of
8 the metabolic heat produced during exercise (Kay and Marino, 2000; Lee et al., 2008a;
9 Mundel et al., 2006). Thermoreceptors in the GI tract (Villanova et al., 1997) may sense
10 this heat sink and signal a reduction in heat loss via convection and sweat evaporation
11 (evidenced by decreased SBF and Tsk) (Banerjee, 1970). A decreased SBF after
12 consumption of a cold fluid bolus has been observed previously (Wimer et al., 1997)
13 but the small serial volume consumed in this study did not alter SBF or heart rate.

14

15 Similarly to previous investigations involving exercise (Galbo et al., 1979; MacLaren et
16 al., 1995) or heat exposure (Jenssen et al., 1988), circulating VIP increased during
17 exercise in the heat. Contrary to our hypothesis, no significant difference in VIP was
18 detected with exposure to ICE versus thermoneutral beverage temperature. Serial cold
19 beverage (ICE) ingestion may not be a strong enough stimulus to overcome the
20 requirement for increased circulating VIP to vasodilate skin for heat loss. This suggests
21 that VIP is not part of the mechanism by which cold beverage consumption improves
22 thermoregulation during prolonged exercise in the heat. No difference in circulating
23 VIP with bolus cold beverage ingestion would suggest that the mechanism by which Tsk
24 is reduced is mediated by other hormones or a neural mechanism. One potential neural
25 mechanism is via stimulation of receptors in the GI tract (Villanova et al., 1997),
26 sending signals to the brain and skin to modify thermoregulation.

1
2 In conclusion, the present study has shown that ice slushy ingestion led to a reduced
3 heat storage and a lower skin temperature at the end of exercise. In addition, plasma
4 VIP increased during exercise and was correlated with Tr, but was not affected by ice
5 slushy ingestion. While ice slushy ingestion is a potentially useful method for enhancing
6 athletic performance in the heat, further research is needed to investigate the
7 mechanism by which cold beverage ingestion affects thermoregulation.

8

1 **References**

- 2 Aoyagi, Y., McLellan, T.M., Shephard, R.J., 1996. Determination of body heat storage:
3 how to select the weighting of rectal and skin temperatures for clothed subjects. *Int.*
4 *Arch. Occup. Environ. Health* 68, 325-336.
- 5 Armstrong, L.E., Hubbard, R.W., Szlyk, P.C., Matthew, W.T., Sils, I.V., 1985. Voluntary
6 dehydration and electrolyte losses during prolonged exercise in the heat. *Aviat. Space*
7 *Environ. Med.* 56, 765-770.
- 8 Banerjee, M.R., 1970. Transient changes in sweating activity of man following ingestion
9 of water at different temperatures. *Int. J. Biometeorol.* 14, 381-390.
- 10 Bennett, L.A.T., Johnson, J.M., Stephens, D.P., Saad, A.R., Kellogg Jr, D.L., 2003.
11 Evidence for a role for vasoactive intestinal peptide in active vasodilatation in the
12 cutaneous vasculature of humans. *J Physiol* 552, 223-232.
- 13 Burdon, C., O'Connor, H., Gifford, J., Shirreffs, S., Chapman, P., Johnson, N., 2010. Effect
14 of drink temperature on core temperature and endurance cycling performance in
15 warm, humid conditions. *J. Sports Sci.* 28, 1147-1156.
- 16 Charkoudian, N., 2003. Skin blood flow in adult human thermoregulation: how it works,
17 when it does not, and why. *Mayo Clin. Proc.* 78, 603-612.
- 18 Galbo, H., Hilsted, J., Fahrenkrug, J., De Muckadell, O.B.S., 1979. Fasting and prolonged
19 exercise increase vasoactive intestinal polypeptide (VIP) in plasma. *Acta Physiol. Scand.*
20 105, 374-377.
- 21 Gisolfi, C.V., Wenger, C.B., 1984. Temperature regulation during exercise: old concepts,
22 new ideas. *Exerc. Sport Sci. Rev.* 12, 339-372.
- 23 Goldman, R.F., Buskirk, E.R., 1961. Body volume measurement by underwater
24 weighing: description of a method, in: J. Brozek, Henschel, A. (Eds.), *Techniques for*
25 *Measuring Body Composition*. National Academy of Science, Washington D.C.
- 26 Havenith, G., Luttikholt, V.G., Vrijkotte, T.G., 1995. The relative influence of body
27 characteristics on humid heat stress response. *Eur. J. Appl. Physiol.* 1995, 3.

- 1 Hilsted, J., Galbo, H., Sonne, B., Schwartz, T., Fahrenkrug, J., de Muckadell, O.B.,
2 Lauritsen, K.B., Tronier, B., 1980. Gastroenteropancreatic hormonal changes during
3 exercise. American Journal of Physiology - Gastrointestinal and Liver Physiology 239,
4 G136-G140.
- 5 Jenssen, T., Haukland, H., Burhol, P., 1988. Brain-gut peptides in sauna-induced
6 hyperthermia. Acta Physiol. Scand. 132, 519-523.
- 7 Kay, D., Marino, F.E., 2000. Fluid ingestion and exercise hyperthermia: implications for
8 performance, thermoregulation, metabolism and the development of fatigue. [Review].
9 J. Sports Sci. 18, 71-82.
- 10 Lee, J.K., Maughan, R.J., Shirreffs, S.M., 2008a. The influence of serial feeding of drinks
11 at different temperatures on thermoregulatory responses during cycling. J. Sports Sci.
12 26, 583-590.
- 13 Lee, J.K., Shirreffs, S.M., 2007. The influence of drink temperature on thermoregulatory
14 responses during prolonged exercise in a moderate environment. J. Sports Sci. 25, 975-
15 985.
- 16 Lee, J.K.W., Shirreffs, S.M., Maughan, R.J., 2008b. Cold drink ingestion improves
17 exercise endurance capacity in the heat. Med. Sci. Sports Exerc. 40, 1637-1644.
- 18 MacLaren, D., Raine, N., O'Connor, A.M., Buchanan, K.D., 1995. Human gastrin and
19 vasoactive polypeptide responses to endurance running in relation to training status and
20 fluid ingested. Clin. Sci. 89, 137-143.
- 21 Montain, S.J., Coyle, E.F., 1992. Influence of graded dehydration on hyperthermia and
22 cardiovascular drift during exercise. J. Appl. Physiol. 73, 1340-1350.
- 23 Mundel, T., King, J., Collacott, E., Jones, D.A., 2006. Drink temperature influences fluid
24 intake and endurance capacity in men during exercise in a hot, dry environment. Exp.
25 Physiol. 91, 925-933.
- 26 Ramanathan, N.L., 1964. A new weighting system for mean surface temperature of the
27 human body. J. Appl. Physiol. 19, 531-533.
- 28 Rowell, L.B., 1986. Human circulation: regulation during physical stress. Oxford
29 University Press, New York.

- 1 Said, S.I., Mutt, V., 1970a. Polypeptide with broad biological activity: isolation from
2 small intestine. *Science* 169(3951):1217-8 169, 1217-1218.
- 3 Said, S.I., Mutt, V., 1970b. Potent peripheral and splanchnic vasodilator peptide from
4 normal gut. *Nature* 225, 863-864.
- 5 Sawka, M.N., Burke, L.M., Eichner, E.R., Maughan, R.J., Montain, S.J., Stachenfeld, N.S.,
6 2007. American College of Sports Medicine position stand. Exercise and fluid
7 replacement. *Med. Sci. Sports Exerc.* 39, 377-390.
- 8 Schaffalitzky de Muckadell, O.B., Fahrenkrug, J., Holst, J.J., Lauritsen, K.B., 1977.
9 Release of vasoactive intestinal polypeptide (VIP) by intraduodenal stimuli. *Scand. J.*
10 *Gastroenterol.* 12, 793-799.
- 11 Siri, W.E., 1956. *Advances in biological and medical physics*. Academic Press, Orlando.
- 12 van der Ploeg, G.E., Gunn, S.M., Withers, R.T., Modra, A.C., Crockett, A.J., 2000.
13 Comparison of two hydrodensitometric methods for estimating percent body fat. *J.*
14 *Appl. Physiol.* 88, 1175-1180.
- 15 Villanova, N., Azpiroz, F., Malagelada, J.R., 1997. Perception and gut reflexes induced by
16 stimulation of gastrointestinal thermoreceptors in humans. *J. Physiol. (Lond).* 502, 215-
17 222.
- 18 Wimer, G.S., Lamb, D.R., Sherman, W.M., Swanson, S.C., 1997. Temperature of
19 ingested water and thermoregulation during moderate-intensity exercise. *Can. J. Appl.*
20 *Physiol.* 22, 479-493.
- 21
- 22

1 **Figure captions:**

2
3
4 **Figure 1:** (a) Rectal temperature; and (b) skin temperature during steady-state exercise
5 with consumption of ICE or CON. * $P < 0.05$ ICE vs CON

6 **Figure 2:** Plasma vasoactive intestinal peptide (VIP) during steady-state exercise in the
7 heat with CON or ICE ingestion. VIP increased with exercise but there were no
8 differences between trials. * significantly different to rest $p < 0.05$

9 **Figure 3:** There was a significant correlation between plasma VIP and both T_{re} and T_{sk}
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

*Highlights (for review)

- The effect of ice-slusly ingestion on body temperature and plasma VIP was examined
- Skin temperature was lower with ice-slusly consumption
- Plasma VIP was not changed with cold beverage ingestion
- There was a correlation between plasma VIP and rectal temperature

Figure

Figure 2

Figure

Figure 3