Journal of Human Performance in Extreme Environments

Volume 12 | Issue 1 Article 6

Published online: 11-16-2015

Changes in Intragastric Temperature Reflect Changes in Heat Stress Following Tepid Fluid Ingestion But Not Ice Slurry Ingestion

Christopher J. Stevens
University of Newcastle, Australia, christopher.j.stevens@uon.edu.au

Ben Dascombe
University of Newcastle, Australia, Ben.Dascombe@newcastle.edu.au

Recommended Citation

Stevens, Christopher J. and Dascombe, Ben (2015) "Changes in Intragastric Temperature Reflect Changes in Heat Stress Following Tepid Fluid Ingestion But Not Ice Slurry Ingestion," *Journal of Human Performance in Extreme Environments*: Vol. 12 : Iss. 1 , Article 6.
DOI: 10.7771/2327-2937.1067
Available at: https://docs.lib.purdue.edu/jhpee/vol12/iss1/6

Changes in Intragastric Temperature Reflect Changes in Heat Stress Following Tepid Fluid Ingestion But Not Ice Slurry Ingestion

Cover Page Footnote

The authors would like to acknowledge the participants for their contribution to the study

Changes in Intragastric Temperature Reflect Changes in Heat Stress Following Tepid Fluid Ingestion But Not Ice Slurry Ingestion

Christopher J. Stevens and Ben J. Dascombe

University of Newcastle, Australia

Abstract

This study examined the effects of fluid and ice slurry ingestion on the relationship between intragastric temperature and rectal temperature in humans during physical activity. The purpose was to identify a technique to quantify changes in heat stress in situations when temperature probes are not feasible and when time constraints do not allow for a period long enough for an indigestible temperature capsule to reach the lower gastrointestinal tract. Eight moderately trained male runners inserted a rectal probe and ingested a telemetric capsule before randomized, crossover, pre-exercise ingestion of 7.5 $mL \cdot kg^{-1} \cdot BM^{-1}$ tepid fluid (22℃) or ice slurry (−1℃). Beverage ingestion was followed by a self-paced endurance running time trial. Average intragastric temperature was significantly lower than average rectal temperature across the run following both fluid (37.9 ± 0.4℃ vs. 38.4 ± 0.2℃; $p=0.003$) and ice slurry ingestion (37.2 ± 0.9 vs. 38.3 ± 0.2; $p=0.009$). However, a strong relationship was observed between measurements following fluid ($r=0.89$) but not ice slurry ($r=0.18$). The average bias ± limits of agreement during the run was 0.46 ± 0.50 following fluid and 1.09 ± 1.68 following ice slurry ingestion, which improved to 0.06 ± 0.76 and 0.65 ± 1.42, respectively when analyzed as delta scores. Intragastric temperature appears to not be a valid measure of absolute core body temperature at baseline or during exercise following either fluid or ice slurry ingestion. However, the relative changes in intragastric temperature during endurance exercise appears to be a strong indicator of systemic heat stress during exercise following ingestion of fluid at 22℃, but not ice slurry at −1℃.

Keywords: temperature measurement, telemetric capsule, biological monitoring, rectal temperature, running

Introduction

Research in extreme environments may be limited by the capacity to measure changes in total body heat stress. In the laboratory, core body temperature is often measured at either the rectum or esophagus with a temperature probe that is highly invasive, uncomfortable and sometimes considered obscene (Moran & Mendal, 2002). More importantly, however, the use of temperature probes for such purposes may constrain research in the field and ecologically valid outcomes where probes must be attached to more cumbersome equipment. For example, use of a temperature probe on a fire-fighter working to control a bushfire or an astronaut in space may severely limit their work capacity. To overcome these limitations, some researchers have substituted rectal thermometry with an indigestible telemetric sensor (capsule) and the subsequent measurement of its surrounding temperature higher up in the gastrointestinal tract (Ihsan, Landers, Brearley, & Peeling, 2010; Stevens, Dascombe, Sculley, Boyko, & Callister, 2013; Yeo, Fan, Nio, Byrne, & Lee, 2012). The telemetric capsule is convenient, allows free movement, field-based measurements and is quick to respond to temperature changes with physical activity (Byrne & Lim, 2007).

The telemetric capsule has been demonstrated to provide valid measurements of rectal temperature consistently across a 36 h period (Ducharme, McLellan, Moroz, Buguet, & Radomski, 2001). However, others have reported significantly lower sensor recordings compared to rectal thermometry when ingested 3–9 h before measurement (Sparling, Snow, & Millard-Stafford, 1993) as well as significantly higher sensor recordings compared to rectal thermometry when ingested 10 h before measurement (Gant, Atkinson, & Williams, 2006). As such, the direction of the bias between measurements has varied across studies. Nevertheless, Byrne and Lim (2007) reviewed the validity research and concluded that, while there was a systematic bias >0.1℃ across 11 studies, 95% limits of agreement were acceptable (within ± 0.4℃) and as such, gastrointestinal temperature appeared to be a valid core temperature measurement technique. However, the reviewers suggested a time of at least 6 h between

The authors would like to acknowledge the participants for their contribution to the study. Correspondence concerning this article should be sent to christopher.j.stevens@uon.edu.au.

http://dx.doi.org/10.7771/2327-2937.1067

ingestion and measurement so the sensor can reach the lower intestine. This represents a methodological limitation that must be overcome given that research on emergency personnel requires a temperature measurement technique that can function immediately following a callout and further, such a method must allow for fluid ingestion.

Although the current data suggest valid telemetric sensor measurements can be acquired from the gastrointestinal tract, only one study investigated the effect of cold fluid ingestion on such measurements. Recently, the ingestion of cold fluid and ice slurry has been a popular area of research to promote hydration, cooling and improved performance in athletes and emergency services personnel (Pryor, Suyama, Guyette, Reis, & Hostler, 2015; Tan & Lee, 2015). A bolus of cold water (250 $mL \cdot h^{-1}$; 5–8℃) significantly decreased the temperature of a capsule ingested immediately prior (capsule 1) vs. a capsule ingested 11.5 h prior (capsule 2) to the first measurement (Wilkinson, Carter, Richmond, Blacker, & Rayson, 2008). A comparison of capsule 2 and rectal temperature demonstrated an average bias of 0.15℃ across 8×30 min bouts of repeated rest and fire-fighting drills. As such, the ingestion of cold water failed to decrease the average gastrointestinal temperature over the 8 h period. No data was reported on the relationship between capsule 1 and rectal temperature, which would have provided insight into the use of stomach (intragastric) temperature for the measurement of core body temperature. Such a core temperature measurement location would allow avoidance of long (6–12 h) and often impractical waiting periods between capsule ingestion and measurement, but may be affected by the ingestion of fluid.

Intragastric temperature is approximately 37℃ and takes 23.8 ± 1.1 min to return to baseline following infusion of 360 mL of cold (4℃) fluid (McArthur & Feldman, 1989). Although it is known that cold beverages have a large, transient effect on intragastric temperature, it is currently unclear if measurements recorded during physical activity following ingestion represent that of core body temperature, or secondly, if a relationship exists by which changes in core temperature can be inferred. Therefore, the aim of the present study was to investigate the relationship between intragastric temperature and rectal temperature during exercise in the heat following ingestion of fluid. Secondly, ice slurry was also investigated due to recent interventions utilizing such a mixture on both athletes and emergency service personnel for improved comfort and performance (Pryor et al., 2015; Stevens et al., 2013).

Methods

Eight trained male runners (age: 27 ± 9 years, height: 179 ± 7 cm, body mass: 75 ± 12 kg, Σ7 skinfolds: 58 ± 27 mm, body fat %: 8.7 ± 6.3) volunteered for the study. Inclusion criteria stipulated participants must have completed a 5 km running time trial in a time between 18–22 min in the last six months. Subjects must have been free of any medical condition that could result in harm. The Human Ethics Research Committee at the University of Newcastle granted approval for the project (UoN H-2012-0311) and participants provided written informed consent prior to engaging in all procedures.

Study Design

Participants performed familiarization followed by two randomized trials involving either pre-exercise fluid (22℃) or ice slurry ingestion (−1℃). Beverage ingestion was followed by a running warm-up and a self-paced 5 km running time trial on a non-motorized treadmill (Curve 3™, Woodway, Waukesha, USA) in an environmental chamber (33℃, 46% relative humidity (RH)). Intragastric and rectal temperatures were measured throughout each trial. The trials were performed at the same time of day and were each separated by 5–10 days to allow complete recovery between the experiments.

Testing Procedures

An anthropometric profile was obtained from each participant consisting of height (217 stadiometer, Seca, Birmingham, UK), body mass (DS-530 electronic scales, Wedderburn, Sydney, Australia) and Σ7 skinfolds (Harpenden Calipers, Baty International, West Sussex, UK). The participants performed a standardized 10 min warm-up (4 min jog, 1 min walk, 4 min run, 1 min walk) prior to the first trial in which speed was recorded for repetition prior to the second trial. The time trials commenced 2 min later from a standing start on the command of the tester. During the time trials, the participants were blinded to all measures except for elapsed distance. A 50 cm fan was placed 1 m in front of the participant and provided a wind speed of 4 $m \cdot s^{-1}$ to simulate the convective cooling of outdoor conditions.

Beverages

A beverage of either tepid fluid (22℃) or ice slurry (−1℃) with a total volume of 7.5 $mL \cdot kg^{-1} \cdot BM^{-1}$ (563 ± 90 mL) was provided in six equal boluses over a 30 min period to ensure uniform ingestion. The beverages were made from sports drink (Gatorade, PepsiCo, New York, USA) and a commercial machine was used to make ice slurry (Sorby Dream 2, SPM Drink Systems, Spilamberto, Italy). The tepid fluid condition was designed to simulate common drinking practice among athletes and the ice slurry condition was designed to simulate the use of a pre-cooling strategy (Garth & Burke, 2013; Ihsan et al., 2010). During the ingestion period, participants sat on a massage table in an air-conditioned room (23℃). Ingestion concluded 8 min prior to the start of the warm-up and 20 min prior to the start of the time trial. Participants were provided with

25 mL of tepid water (22℃) following the warm-up and at the 2 km and 4 km marks of the time trial to simulate serial drinking during physical activity. Participants were not to use this water for body cooling and were refrained from any additional ingestion of food or drink.

Temperature Measurements

Rectal temperature was measured continuously with a probe inserted 10 cm beyond the anal sphincter connected to a 4600 thermometer (Measurement Specialties, Ohio, USA) and recorded with ThermalView software at 1 Hz (Alpha Technics, California, USA). Intragastric temperature was also measured continuously with a Vital Sense telemetric capsule (MiniMitter Corporation, Oregon, USA). Capsule accuracy was checked in a water bath maintained at 37℃ and any inaccurate capsules (>0.1℃) were eliminated. The capsule was ingested 10 min prior to the first measurement with 25 mL of warm water (37℃) so not to influence baseline recordings. One-minute averages of temperatures were recorded prior to beverage ingestion and 5 min post ingestion. Temperatures were once again measured at the end of the warm-up phase prior to the start of the time trial '0 km'. During the time trial the temperature measurements were averaged across each 1 km interval and were also recorded immediately following completion.

Intensity Measurements

Heart rate was continuously measured at 1 Hz by a Garmin 910XT monitor (Garmin Ltd., Schaffhausen, Switzerland) and rating of perceived exertion was measured at the end of each kilometer using the Borg CR-10 scale (Borg, 1982) to monitor physiological and perceptual intensity during the 5 km running time trials.

Analysis

All results are reported as means ± SD, with normality assessed using a Kolmogorov-Smirnov test. Differences between temperature measurements were analyzed using a condition × time repeated measures analysis of variance (ANOVA). Where main effects occurred, paired sample t-tests were used to identify significant differences between measurements. Paired sample t-tests were also used to compare environmental temperatures, running performance times, average heart rate and rating of perceived exertion between trials. The level of agreement between temperatures was assessed using the 95% limits of agreement (LoA) method (Bland & Altman, 1986). The LoA are reported as bias ± (1.96*SD of the differences between paired measurements). A systematic bias of <0.1℃ and 95% LoA of less than ±0.4℃ were delimited as being required for accepting that two methods agree (Byrne & Lim, 2007). A Pearson product–moment correlation was used to assess the relationship between temperature measurements. Alpha (p) was set at <0.05 and analyses were performed with SPSS software V22.0 (IBM Corporation, Somers, New York, USA).

Results

Average intragastric temperature was significantly lower than average rectal temperature across the run following both fluid (37.9 ± 0.4℃ vs. 38.4 ± 0.2℃; $p=0.003$) and ice slurry ingestion (37.2 ± 0.9 vs. 38.3 ± 0.2; $p=0.009$). Figure 1 shows all temperature measurements and their delta scores across the two trials. In both trials, intragastric temperature was significantly ($p<0.05$) lower than rectal temperature at all time points (Figure 1A and 1B). When the difference in starting temperature was accounted for and data were analyzed as delta scores, intragastric temperature was significantly ($p<0.05$) lower than rectal temperature immediately following the ingestion periods (Figure 1C and 1D). In the ice slurry trial, this difference persisted throughout the warm-up and the first kilometer of the run (Figure 1D).

Table 1 shows the bias, limits of agreement and Pearson's product–moment correlations for the intragastric temperature and rectal temperature measurements. Figure 2 shows Bland-Altman plots of mean temperature responses and the difference between the two measurements during the run. The average LoA during the run was 0.46 ± 0.50℃ following fluid and 1.09 ± 1.68℃ following ice slurry ingestion. When the data were analyzed as delta scores, the average LoA was reduced to 0.06 ± 0.76℃ following tepid fluid ingestion and 0.65 ± 1.42℃ following ice slurry ingestion. The slope of the trend lines suggests that the validity between the two measures improved as body temperature increased.

All data sets were normally distributed ($p>0.05$). There were no significant differences between environmental temperatures, running performance times, mean heart rates or ratings of perceived exertion ($p>0.05$). One participant was removed from the fluid trial owing to equipment failure.

Discussion

In the present study, pre-beverage baseline intragastric and rectal temperatures were significantly different and demonstrated an unacceptable level of agreement. The bias was twice that reported previously, when the temperatures were averaged over a one-hour period with fluid ingestion at 37℃ (Ducharme et al., 2001). However, no LoA were presented and therefore it is unclear if this bias was consistent across the cohort. The data were also collected differently between studies; a 1 min average, 10 min after capsule ingestion and following a 40 min fast in the present study, compared to a one-hour average in the previous study (Ducharme et al., 2001). As such, greater capsule transit time and/or data filtering may be responsible for

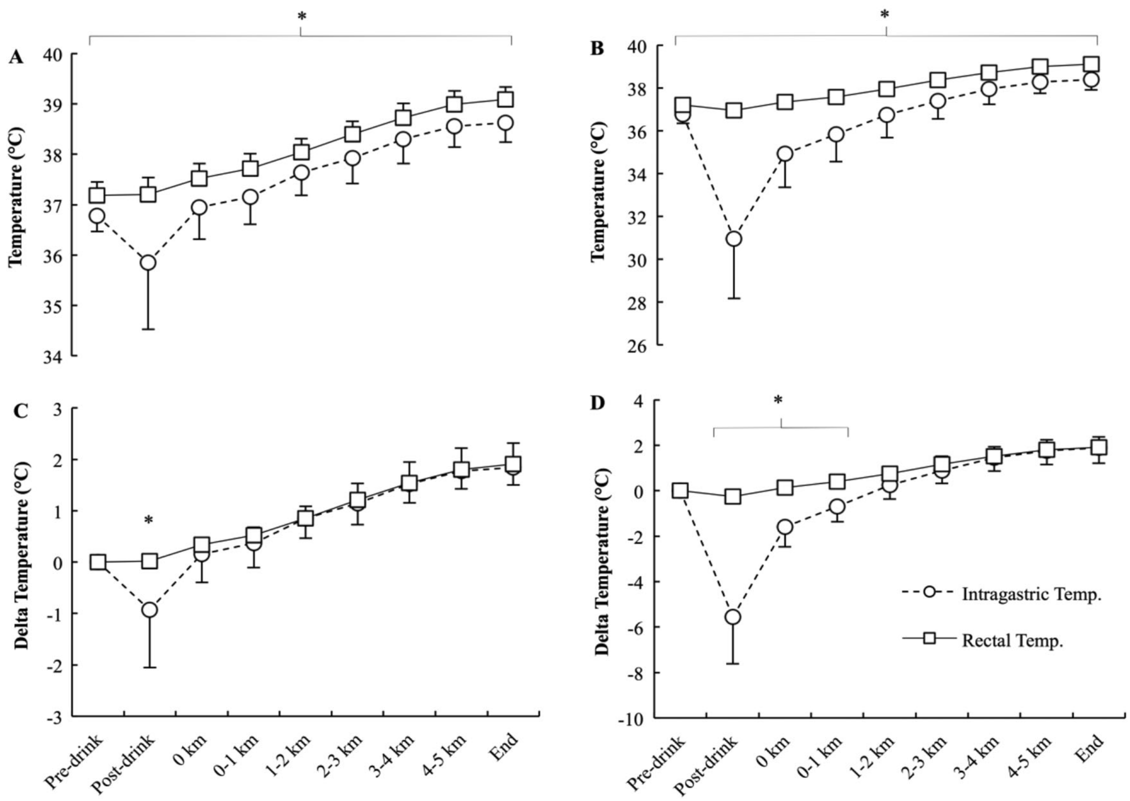

Figure 1. Measurements of intragastric temperature and rectal temperature with A) tepid fluid and B) ice slurry; and their delta scores with C) tepid fluid and D) ice slurry (values are means ± SD). *denotes significant differences, $p<0.05$.

improved bias in the previous study (Ducharme et al., 2001). The baseline bias in present study is strengthened by the consistency between both trials (see Table 1).

As baseline intragastric and rectal temperatures were significantly different, it is not surprising that subsequent absolute measurements were also dissimilar. When the difference in baseline measurements was removed and the data analyzed as delta scores, there was great improvement observed in the bias across both trials (see Figure 1C and 1D). However, the same cannot be said for the LoA, as the use of the delta scores meant the difference between measurements could be positive or negative with the same magnitude (due to a range in starting temperatures), increasing the variation (see Figure 2C and 2D). The delta scores for intragastric temperature mirrored the trend of rectal temperature across the second half of the running time trials, after the cooling effect of the pre-exercise beverages diminished. Such a response was observed despite serial drinking of small volumes of fluid after the warm-up and during the run. Therefore, it is apparent that the capsule responds consistently to increases in core temperature with exercise and is not simply governed by the contents of the stomach. As such, the monitoring of intragastric temperature with a telemetric capsule may be

Table 1
Bias, limits of agreement and Pearson's product–moment correlations for rectal temperature and intragastric temperature measurements.

	Tepid fluid ingestion		Ice slurry ingestion	
	Bias ± 95% LoA	*r* (90% CI)	Bias ± 95% LoA	*r* (90% CI)
Pre-drink	0.40 ± 0.50	0.63 (−0.07–0.92)	0.44 ± 0.63	0.64 (0.03–0.91)
Post-drink	1.35 ± 2.09	0.83 (0.34–0.96)	5.98 ± 5.27	0.39 (−0.31–0.82)
0 km	0.58 ± 0.53	0.69 (0.03–0.93)	2.42 ± 2.95	0.29 (−0.42–0.77)
0–1 km	0.56 ± 0.65	0.86 (0.44–0.97)	1.76 ± 2.36	0.37 (−0.34–0.81)
1–2 km	0.41 ± 0.52	0.84 (0.36–0.97)	1.21 ± 2.03	0.26 (−0.44–0.76)
2–3 km	0.47 ± 0.57	0.91 (0.61–0.98)	0.96 ± 1.63	0.18 (−0.51–0.72)
3–4 km	0.43 ± 0.58	0.83 (0.36–0.97)	0.76 ± 1.42	0.12 (−0.55–0.69)
4–5 km	0.44 ± 0.52	0.78 (0.22–0.95)	0.74 ± 1.07	0.10 (−0.56–0.68)
End	0.46 ± 0.49	0.77 (0.19–0.95)	0.72 ± 1.06	0.03 (−0.60–0.65)
0–5 km	0.46 ± 0.50	0.89 (0.55–0.98)	1.09 ± 1.68	0.18 (−0.50–0.73)

CI = confidence interval, LoA = limits of agreement, *r* = Pearson's product-moment correlation.

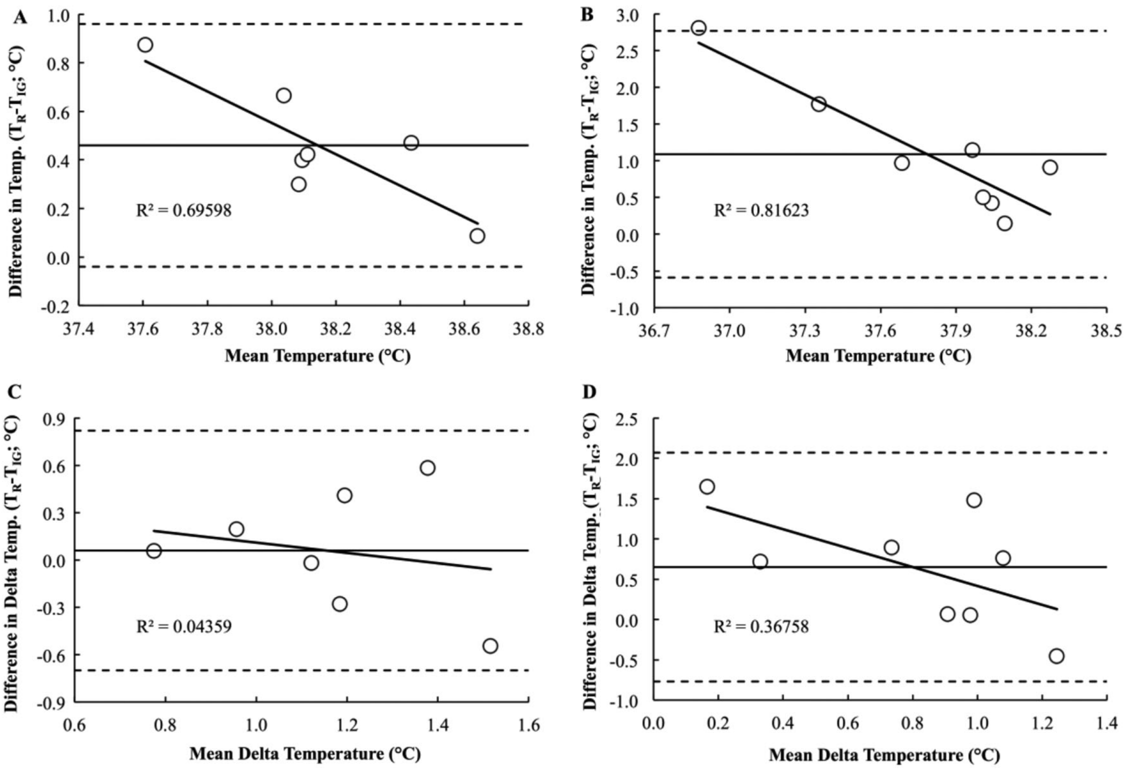

Figure 2. Bland-Altman plots of mean values and the difference between rectal temperature (T_R) and intragastric temperature (T_{IG}) during the 5 km run with A) tepid fluid, B) ice slurry and their delta scores with C) tepid fluid and D) ice slurry. Thick solid line represents the bias, and dashed lines represent the limits of agreement.

useful to quantify the general trend of whole body heat stress during exercise regardless of pre-exercise beverage temperature. This is especially important when rectal thermometry is not appropriate and the recommended 6–10 h waiting period between capsule ingestion and measurement is not feasible (Wilkinson et al., 2008).

Although tepid fluid had a transient effect on intragastric temperature, ice slurry had a much larger and longer lasting effect. Following tepid fluid ingestion, the bias returned to baseline within the second kilometer of the run and remained stable thereafter. As such, a strong correlation was observed between temperature measurements across the run (r=0.89). Therefore, changes in intragastric temperature predicted the change in rectal temperature following fluid ingestion, allowing the magnitude of core temperature increase during exercise to be inferred. Following ice slurry ingestion, however, the bias consistently decreased over time and failed to return to baseline (albeit it was very close by the run cessation). As such, a very weak correlation was observed between temperature measurements across the run (r=0.18). During exercise following ice slurry ingestion, intragastric temperature increased rapidly, which is not a typical representation of changes in systemic heat stress. As a result, intragastric temperature cannot be used to predict the specific magnitude of change in core temperature following ice slurry ingestion. We confirm that ice slurry has a lasting effect on intragastric temperature that persists for greater than 20 min (Sun, Houghton, Read, Grundy, & Johnson, 1988; Wilkinson et al., 2008) and that a 10 min running warm-up is insufficient to negate such an effect.

The temperature measurements in both trials became more similar over time and demonstrated an increase in heat stress (see trend lines of Figure 2). As the accuracy of measurement improved however, the correlations became weaker across each interval of the run in both trials (see Table 1). This is likely a result of the individual responses to exercise heat stress that may have been mediated by differences in body mass (Marino, Lambert, & Noakes, 2004) and/or acclimatization (Lorenzo, Halliwill, Sawka, & Minson, 2010). Consequently, their temperature measurements became more similar earlier in the time trial, disrupting the consistency of the relationship between the temperature measurements. Such a finding highlights the importance of using a cohort likely to experience a similar response to exercise heat stress for thermoregulatory research.

In conclusion, the present study has demonstrated that intragastric temperature is not a valid measure of absolute core body temperature at baseline, or during exercise following fluid or ice slurry ingestion. However, the use of delta scores provides a measure with acceptable bias and a strong correlation exists between temperature measurements during exercise following fluid ingestion. In contrast, ice slurry had a large and long lasting effect on intragastric temperature with minimal effect on rectal temperature. Therefore, the measurements following ice slurry ingestion had unacceptable bias and LoA and further, a very weak correlation was observed. Overall, the relative change in intragastric temperature reflects changes in systemic heat stress during exercise following ingestion of fluid at 22℃, but not ice slurry at −1℃ during a running time trial.

References

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, *1*, 307–310.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports & Exercise*, *14*, 377–381.

Byrne, C., & Lim, C. L. (2007). The ingestible telemetric body core temperature sensor: a review of validity and exercise applications. *British Journal of Sports Medicine*, *41*, 126–133.

Ducharme, M. B., McLellan, T. M., Moroz, D., Buguet, A., & Radomski, M. W. (2001). A 36 hour comparison of core temperature at rest and during exercise using rectal probe and pill telemetry (abstract). *The Australian Physiological & Pharmacological Society*, *32*(2), 28.

Gant, N., Atkinson, G., & Williams, C. (2006). The validity and reliability of intestinal temperature during intermittent running. *Medicine and Science in Sports & Exercise*, *38*, 1926–1931.

Garth, A. K., & Burke, L. M. (2013). What do athletes drink during competitive sporting activities? *Sports Medicine*, *43*, 539–564.

Ihsan, M., Landers, G., Brearley, M., & Peeling, P. (2010). Beneficial effects of ice ingestion as a precooling strategy on 40-km cycling time-trial performance. *International Journal of Sports Physiology & Performance*, *5*, 140–151.

Lorenzo, S., Halliwill, J. R., Sawka, M. N., & Minson, C. T. (2010). Heat acclimation improves exercise performance. *Journal of Applied Physiology*, *109*, 1140–1147.

Marino, F. E., Lambert, M. I., & Noakes, T. D. (2004). Superior performance of African runners in warm humid but not in cool environmental conditions. *Journal of Applied Physiology*, *96*, 124–130.

McArthur, K. E., & Feldman, M. (1989). Gastric acid secretion, gastrin release, and gastric emptying in humans as affected by liquid meal temperature. *American Journal of Clinical Nutrition*, *49*, 51–54.

Moran, D. S., & Mendal, L. (2002). Core temperature measurement: methods and current insights. *Sports Medicine*, *32*, 879–885.

Pryor, R. R., Suyama, J., Guyette, F. X., Reis, S. E., & Hostler, D. (2015). The Effects of Ice Slurry Ingestion before Exertion in Wildland Firefighting Gear. *Prehospital Emergency Care*, *19*, 241–246.

Sparling, P. B., Snow, T. K., & Millard-Stafford, M. L. (1993). Monitoring core temperature during exercise: ingestible sensor vs. rectal thermistor. *Aviation, Space & Environmental Medicine*, *64*, 760–763.

Stevens, C., Dascombe, B., Sculley, D., Boyko, A., & Callister, R. (2013). Ice slurry ingestion during cycling improves Olympic distance triathlon performance in the heat. *Journal of Sports Sciences*, *31*, 1271–1279.

Sun, W. M., Houghton, L. A., Read, N. W., Grundy, D. G., & Johnson, A. G. (1988). Effect of meal temperature on gastric emptying of liquids in man. *Gut*, *29*, 302–305.

Tan, P. M., & Lee, J. K. (2015). The role of fluid temperature and form on endurance performance in the heat. *Scandinavian Journal of Medicine & Science in Sports, 25 Suppl 1*, 39–51.

Wilkinson, D. M., Carter, J. M., Richmond, V. L., Blacker, S. D., & Rayson, M. P. (2008). The effect of cool water ingestion on gastrointestinal pill temperature. *Medicine and Science in Sports & Exercise*, *40*, 523–528.

Yeo, Z. W., Fan, P. W., Nio, A. Q., Byrne, C., & Lee, J. K. (2012). Ice slurry on outdoor running performance in heat. *International Journal of Sports Medicine*, *33*, 859–866.