Prediction of core temperature during prolonged cold water immersion in thermally protected men and women

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Background

- Thermoregulation during cold water immersion has strong associations with:
  - Water temperature
  - Exposure duration
  - Metabolic heat production
  - Insulative and/or thermal protection
- Predictive modeling of core temperature and shivering responses in cold conditions appropriately forecast hypothermia and prevent unfavorable outcomes
- Planned dive operations would benefit from the inclusion of thermal protection garments to accurately plan exposure limits and increase mission efficiency

Methods

Aim:

Provide a preliminary model to predict core temperature response during cold water immersion while wearing a 7mm neoprene wetsuit

- Secondary analysis of pooled data from 5 completed studies
  - Cold water immersion from 1-4 hours
  - 7mm wetsuit, boots, gloves, and hood
  - Subject morphometrics
    - age, sex, height, mass, body mass index, body surface area, body fat percent

Study No.	Participants [Female]	Age (y)	Weight (kg)	Height (cm)	BMI ($kg \cdot m^{-2}$)	Body Fat (%)	BSA (m^2)
1	12 [6]	23 (2)	70.4 (12.4)	171 (10)	23.9 (2.5)	16.1 (6.4)	1.82 (0.2)
2	14 [0]	27 (4)	78.9 (8.1)	175 (6)	25.7 (1.9)	n/a	1.94 (0.1)
3	9 [0]	23 (1)	83.7 (7.0)	178 (8)	26.5 (2.0)	17.4 (5.0)	2.02 (0.1)
4	9 [4]	25 (2)	68.7 (13.3)	169 (9)	24.0 (2.5)	19.3 (5.1)	1.78 (0.2)
5	7 [0]	23 (2)	79.6 (10.4)	176 (8)	25.8 (2.4)	11.3 (3.6)	1.96 (0.2)
AVG	**51 [10]**	**24 (2)**	**76.3 (6.4)**	**174 (4)**	**25.2 (1.2)**	**16.0 (3.4)**	**1.9 (0.1)**

Study No.	Total Immersions	Immersion Conditions			Immersion Position and Study Protocol
		Water Temp (°C)	Duration (min)	Depth	
1	24	25 10	60	1.0 ATA	Seated rest - Dexterity testing at 15 and 45 min of immersion
2	28	25 15	201 (11) 204 (12)	1.6 ATA	Seated rest – Carotid body chemosensitivity testing during immersion
3	18	10	240	1.0 ATA	Seated rest – Fully submersed in salt water (salinity: 23.1 g/L) breathing surface supplied air
4	18	20	240	1.0 ATA	Seated Rest – Breathing surface supplied air OR Breathing 100% O2
5	21	18	240	1.0 ATA	Seated Rest
AVG	**109**	**17.6 (5.4)**	**190 (72)**	-	-

Model Development

- Core temperature change (ΔTc) = Final – Baseline (min 0) core temperature

- A mixed-effects model was fitted with a linear step wise regression analysis using clustering effect (random intercept) for subjects that repeated multiple conditions
  - Variables of interest (i.e. subject morphometrics, water temperature, immersion time) were reduced to significance ($p<0.15$)
  - Potential predictors included body mass index (BMI) OR body surface area (BSA)

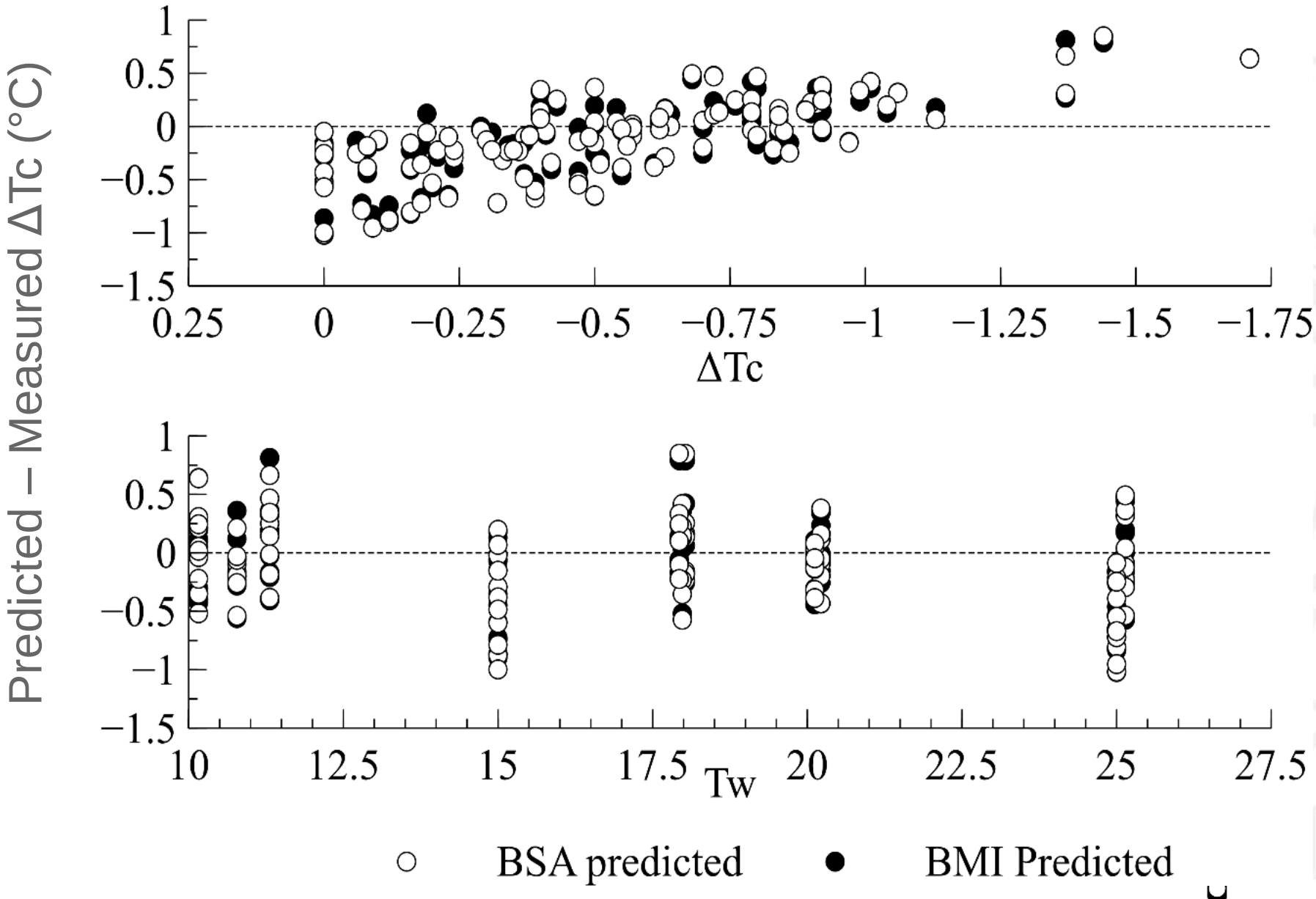
Results

- Best fit model ($p<0.001$) included the predictors of BMI, immersion time (I_t), water temperature (T_w), body fat percent (BF%), and $I_t x T_W$ interaction (all $p<0.05$)

$$\Delta Tc\ (°C) = -2.694 + 0.0427(BMI) + 0.0037(I_t) + 0.0337(T_W) + 0.0302(BF\%) - 0.0002(I_t x T_W)$$

Application:

- Predicted ΔT_C for an average male during a 3 h submersion in 15°C T_W is -0.55°C
- True average ΔT_C was -0.52 ± 0.36°C


Predicted – Measured ΔTc (°C)
1
0.5
0
−0.5
−1
−1.5
0.25
0
−0.25
−0.5
−0.75
−1
−1.25
−1.5
−1.75
ΔTc
10
12.5
15
17.5
20
22.5
25
27.5
Tw
BSA predicted
BMI Predicted

Considerations

- The best fit model to predict core temperature change included water temperature, exposure duration, BMI, and body fat percent
- Thermal protection safeguards core temperature and extends exposure time, and should be considered when planning dive operations
- This preliminary analysis provides two models to predict ΔT_C while wearing a 7mm wetsuit in cold water for up to four hours of resting conditions, and its application may extend to light exercise, but further research is needed
- Future work to expand this model should include additional wetsuit thickness, varying depths, and increased metabolic heat production

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QUESTIONS

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