Thermorégulation

Froid vs Chaud

Thermorégulation

Thermogénèse

<u>Humains</u> = homéothermes + endotherme (≠ ectotherme)

T° constante, 35 – 42°C (moyenne ~37,2°C)

produit une T° corporelle par vie cellulaire, généralement > T ° environnement

△ *sommeil, digestion, hydratation, excitation, exercice, travail, fièvre*

<u>Environnement Thermoneutre</u>

Compartiments a l’équilibre

Pas de transfert d’énergie entre le corps et l’environnement

<u>Stress Thermique</u>

Conserve ou dissipe la chaleur = maintien de la T° corporelle = thermorégulation

Stratégies = physiologiques, comportementales

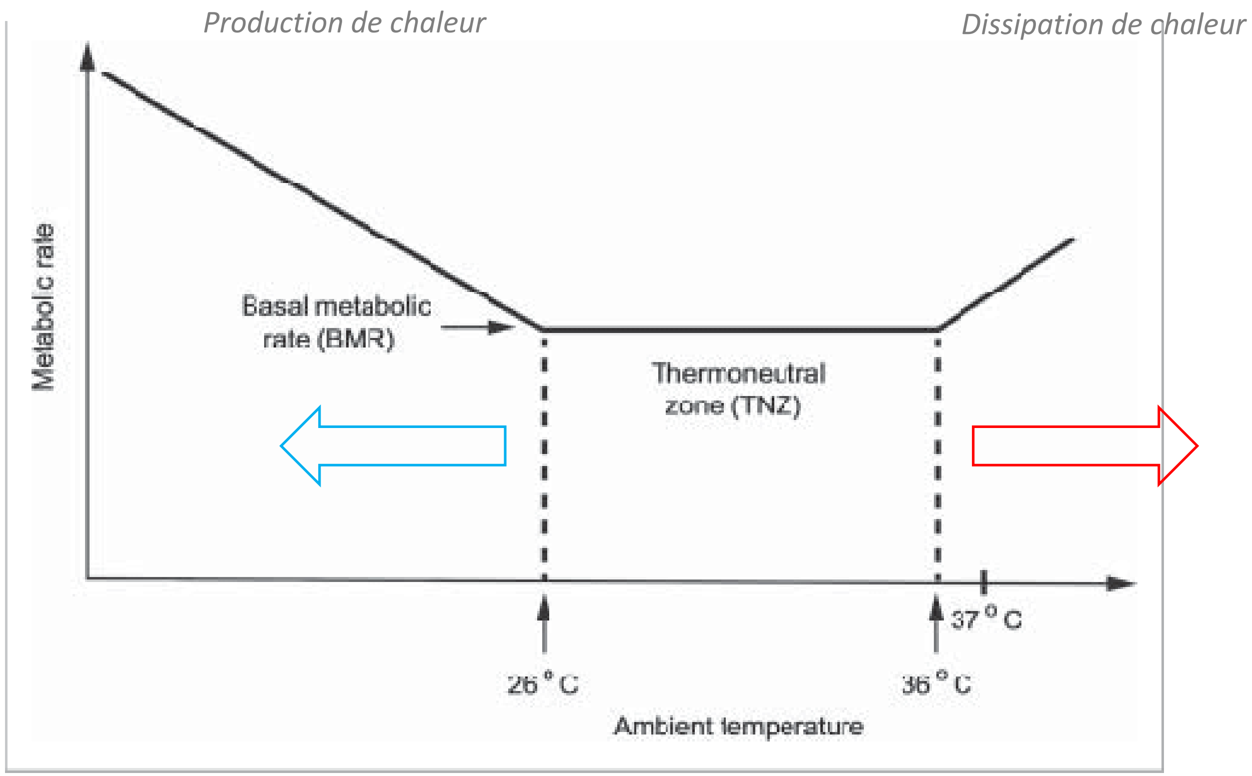
pour atteindre / conserver l’équilibre

Thermorégulation

Thermogénèse

Zone thermoneutre

1 MET



3,5-5 mL/min/kg
0,25-0,35 L/min
5-9 kJ/min
85-150 J/s

ZTN : production = dissipation

Thermorégulation

Thermogénèse

<u>Effet de l'exercice</u>

Contraction musculaire = produit encore + de chaleur

Hydrolyse de l'ATP = ~70-80% de l'énergie convertie en chaleur

⌦ *quand il fait froid*

Conserver la chaleur = bénéfice ! (jusqu'à un point)

Habits (isolation humidité, vent)

Roal Amundsen = "the body is a furnace"

⌦ *quand il fait chaud*

Dissiper l'énergie…

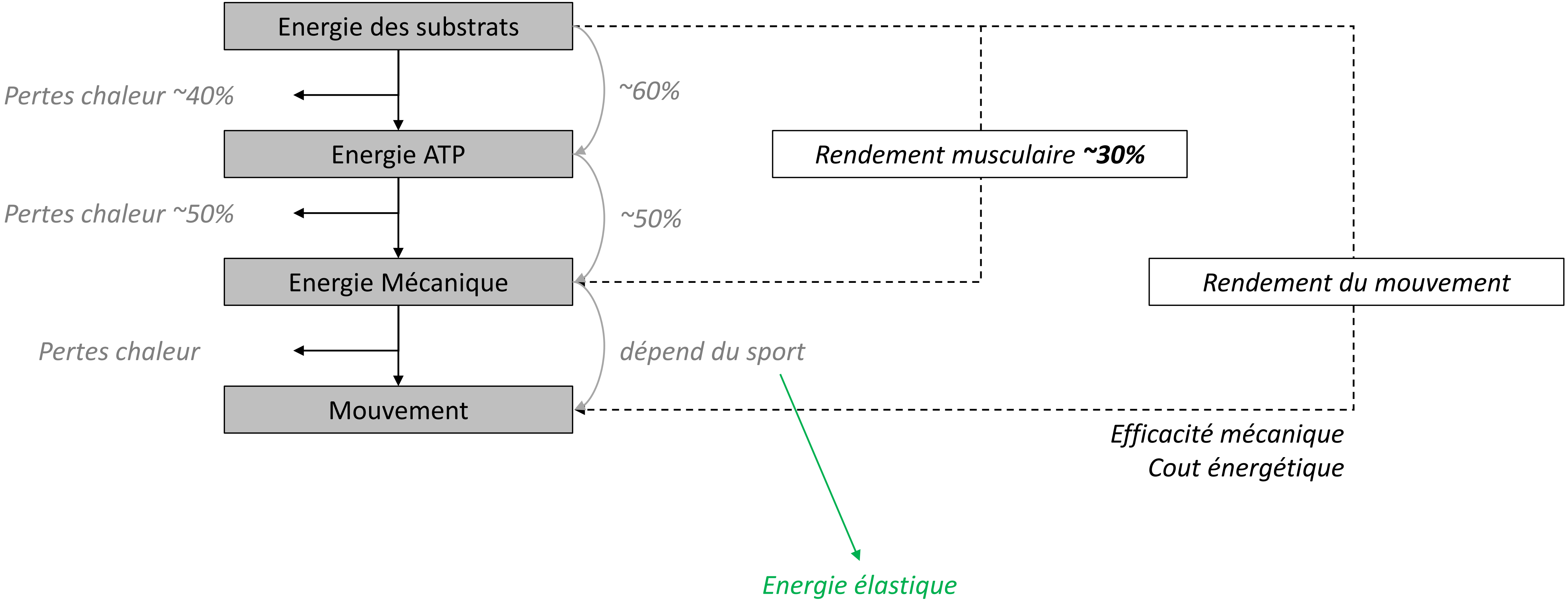
THERMOREGULATION

Balance entre chaleur apportée et chaleur dissipée

Thermorégulation

Thermogénèse

<u>Effet de l'exercice</u>



Thermorégulation

Régulation

Contrôle hypothalamique

Centre de coordination pour les stratégies de thermorégulation

« thermostat » 37,2 ± 1°C

La tête est très vascularisée

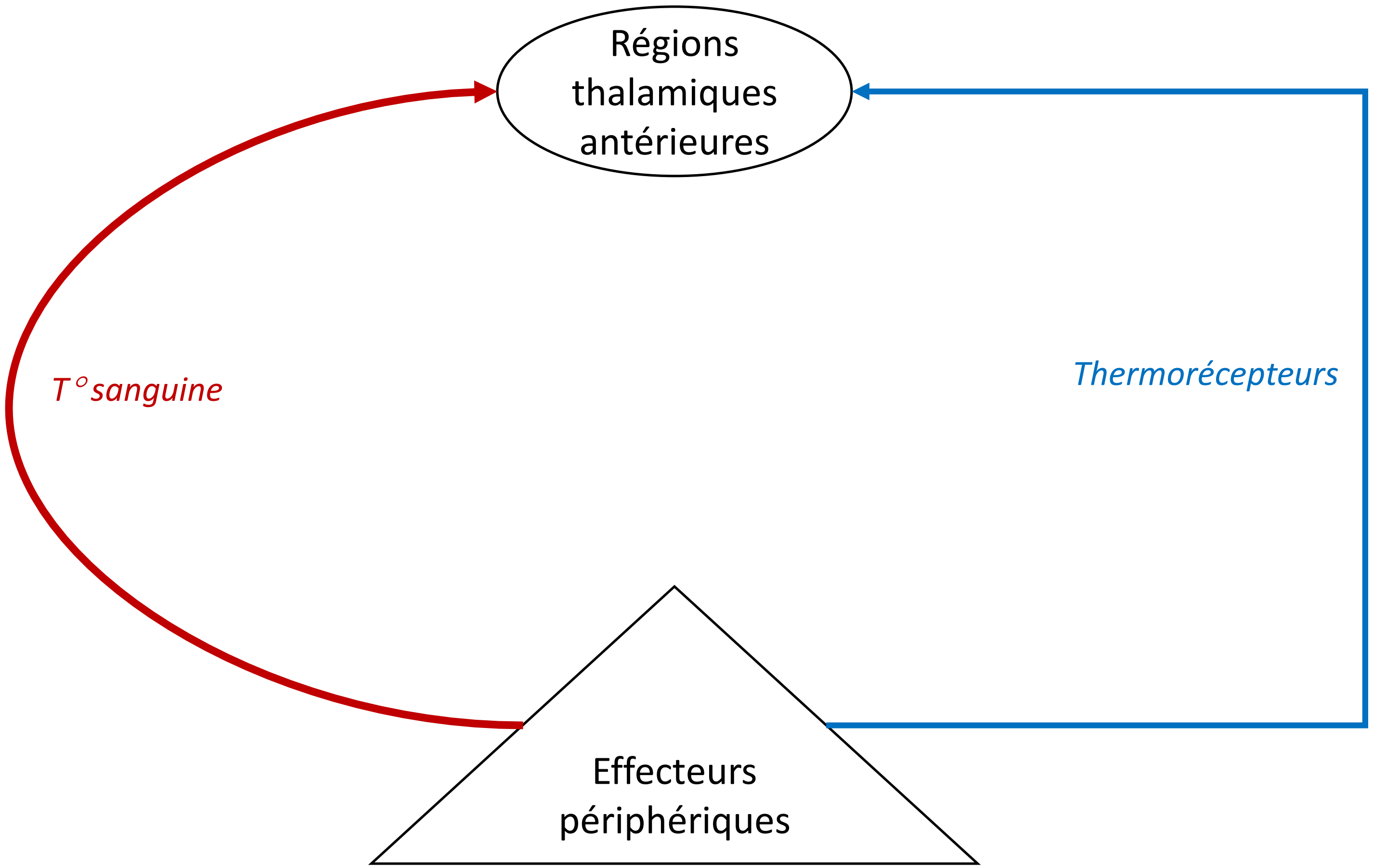
Traite 2 types d'information

- T° sanguine
- Informations sensitives de thermorécepteurs centraux et périphériques

Thermorégulation

Régulation

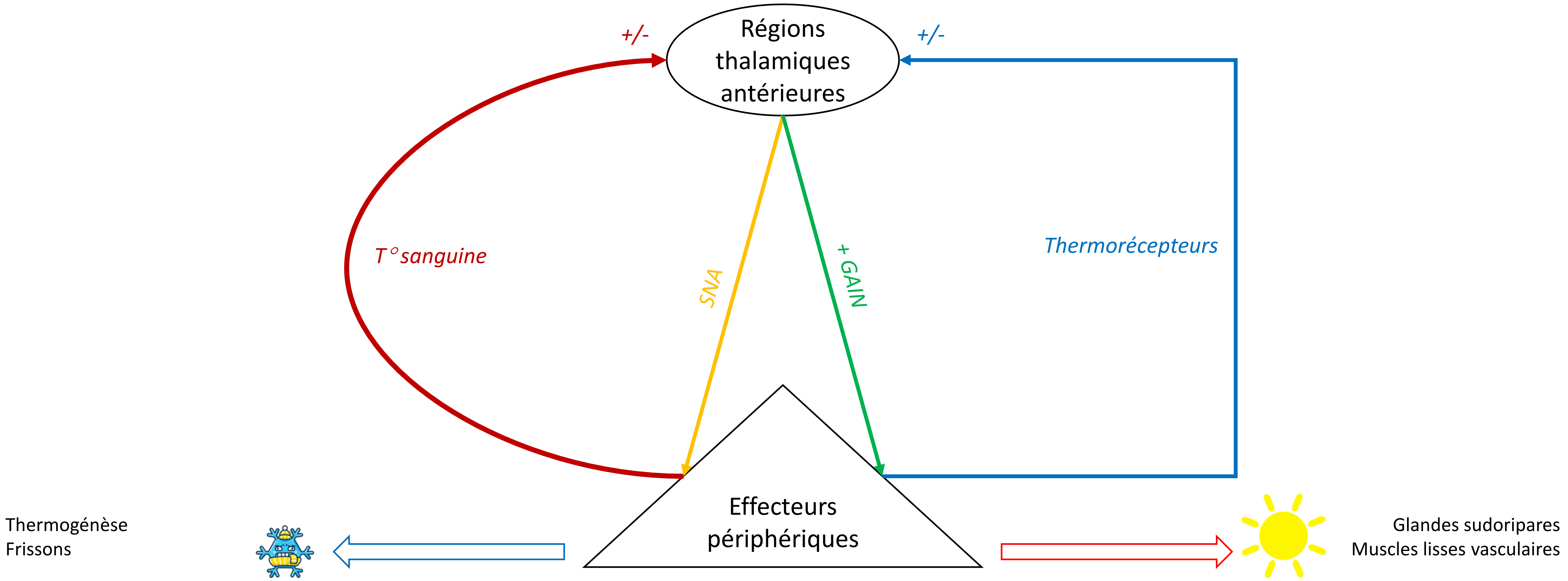
<u>Contrôle hypothalamique</u>



Thermorégulation

Régulation

Contrôle hypothalamique



Thermorégulation

Transferts de chaleur

<u>Avec ou sans contact physique</u>

- **Conduction**

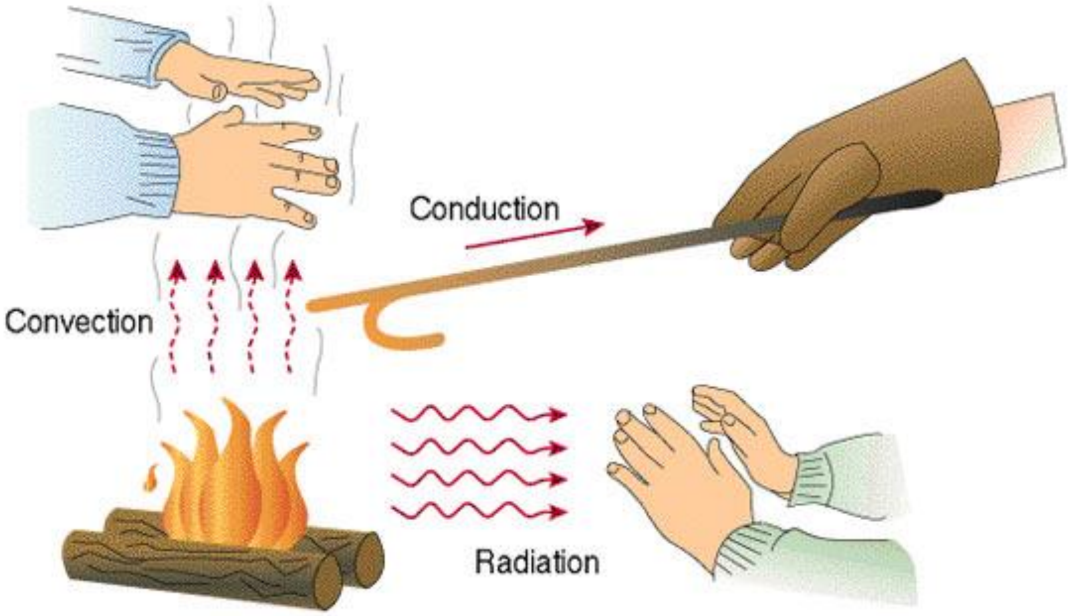
  avec contact = diffusion microscopique

- **Convection**

  avec contact = mouvement collectif des molécules dans un fluide
  utilise le principe de conduction a une échelle encore + petite (uniquement dans l'air = n'existe pas dans l'espace)

- **Radiation**

  sans contact : ondes électromagnétiques
  plus les ondes sont courtes moins elles ont d'énergie
  infrarouge = chaleur IR
  ultraviolets = radiation UV (coup de soleil)



Thermorégulation

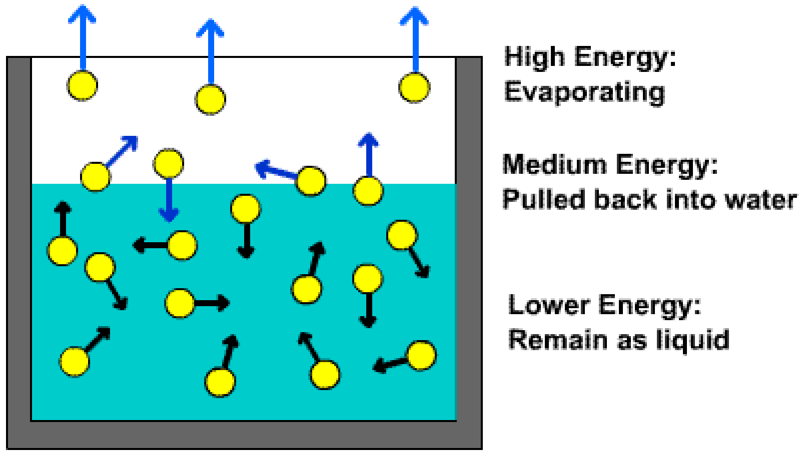
Transferts de chaleur

<u>Avec ou sans contact physique</u>

- **Refroidissement par évaporation**

  vaporisation de liquide (changement de phase), vers l'air environnant
  = phase liquide a gazeuse *seulement si l'air n'est pas saturé en eau*

Pourquoi ?
- quand les molécules d'un liquide se réchauffent, elles gagnent de l'énergie cinétique
- elles s'évaporent lorsque cette énergie cinétique dépasse la force intermoléculaire
- les molécules restantes ont (collectivement) une énergie cinétique moindre
- leur température baisse



Thermorégulation

Chaleur

Ressenti

Ressenti dans le froid

Varie surtout en fonction du vent

WIND CHILL INDEX — Air Temperature °C

WIND SPEED 10m km/hr

0	16	14	12	10	8	6	4	2	0	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32	-34	-36	-38	-40
4	16	14	12	10	8	6	3	1	-1	-3	-6	-8	-10	-12	-14	-17	-19	-21	-23	-26	-28	-30	-32	-35	-37	-39	-41	-43	-46
6	16	14	12	9	7	5	3	0	-2	-4	-7	-9	-11	-14	-16	-18	-20	-23	-25	-27	-30	-32	-34	-37	-39	-41	-43	-46	-48
8	16	14	11	9	7	4	2	0	-3	-5	-7	-10	-12	-14	-17	-19	-22	-24	-26	-29	-31	-33	-36	-38	-40	-43	-45	-47	-50
10	16	13	11	9	6	4	1	-1	-3	-6	-8	-10	-13	-15	-18	-20	-22	-25	-27	-30	-32	-34	-37	-39	-42	-44	-46	-49	-51
12	16	13	11	8	6	3	1	-1	-4	-6	-9	-11	-13	-16	-18	-21	-23	-26	-28	-30	-33	-35	-38	-40	-43	-45	-47	-50	-52
14	15	13	10	8	6	3	1	-2	-4	-7	-9	-12	-14	-16	-19	-21	-24	-26	-29	-31	-34	-36	-39	-41	-43	-46	-48	-51	-53
16	15	13	10	8	5	3	0	-2	-5	-7	-10	-12	-15	-17	-19	-22	-24	-27	-29	-32	-34	-37	-39	-42	-44	-47	-49	-52	-54
18	15	13	10	8	5	3	0	-2	-5	-7	-10	-12	-15	-17	-20	-22	-25	-27	-30	-32	-35	-37	-40	-42	-45	-47	-50	-52	-55
20	15	12	10	7	5	2	0	-3	-5	-8	-10	-13	-15	-18	-20	-23	-25	-28	-30	-33	-36	-38	-41	-43	-46	-48	-51	-53	-56
22	15	12	10	7	5	2	0	-3	-6	-8	-11	-13	-16	-18	-21	-23	-26	-28	-31	-34	-36	-39	-41	-44	-46	-49	-51	-54	-56
24	15	12	10	7	4	2	-1	-3	-6	-8	-11	-13	-16	-19	-21	-24	-26	-29	-31	-34	-37	-39	-42	-44	-47	-49	-52	-54	-57
26	15	12	9	7	4	2	-1	-3	-6	-9	-11	-14	-16	-19	-22	-24	-27	-29	-32	-34	-37	-40	-42	-45	-47	-50	-52	-55	-58
28	14	12	9	7	4	2	-1	-4	-6	-9	-11	-14	-17	-19	-22	-24	-27	-30	-32	-35	-37	-40	-43	-45	-48	-50	-53	-56	-58
30	14	12	9	7	4	1	-1	-4	-6	-9	-12	-14	-17	-20	-22	-25	-27	-30	-33	-35	-38	-40	-43	-46	-48	-51	-53	-56	-59
32	14	12	9	6	4	1	-1	-4	-7	-9	-12	-15	-17	-20	-22	-25	-28	-30	-33	-36	-38	-41	-43	-46	-49	-51	-54	-57	-59
34	14	12	9	6	4	1	-2	-4	-7	-10	-12	-15	-17	-20	-23	-25	-28	-31	-33	-36	-39	-41	-44	-46	-49	-52	-54	-57	-60
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44	14	11	8	6	3	0	-2	-5	-8	-10	-13	-16	-18	-21	-24	-27	-29	-32	-35	-37	-40	-43	-45	-48	-51	-54	-56	-59	-62
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48	14	11	8	6	3	0	-3	-5	-8	-11	-13	-16	-19	-22	-24	-27	-30	-32	-35	-38	-41	-43	-46	-49	-51	-54	-57	-60	-62
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54	14	11	8	5	3	0	-3	-6	-8	-11	-14	-17	-19	-22	-25	-28	-30	-33	-36	-39	-41	-44	-47	-50	-52	-55	-58	-61	-63
56	13	11	8	5	2	0	-3	-6	-9	-11	-14	-17	-20	-22	-25	-28	-31	-33	-36	-39	-42	-44	-47	-50	-53	-55	-58	-61	-64
58	13	11	8	5	2	0	-3	-6	-9	-11	-14	-17	-20	-22	-25	-28	-31	-34	-36	-39	-42	-45	-47	-50	-53	-56	-58	-61	-64
60	13	11	8	5	2	0	-3	-6	-9	-12	-14	-17	-20	-23	-25	-28	-31	-34	-36	-39	-42	-45	-48	-50	-53	-56	-59	-61	-64

From -25 to -34°: Frostbite likely after prolonged skin exposure to wind
From -35 to -60°: Frostbite possible in less than 10 minutes
Below -60°: Frostbite possible in less than 2 minutes

Thermorégulation

Chaleur

<u>Ressenti</u>

Ressenti dans le chaud

Varie surtout en fonction de l'humidité

Humidex from Temperature and Relative Humidity Readings

Relative Humidity (%) \ Temperature (C)	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
100	29	31	33	35	37	39	41	43	45	48	50	53	55	58									
95	28	30	32	34	36	38	40	42	44	47	49	51	54	56	59								
90	28	30	31	33	35	37	39	41	43	45	48	50	52	55	57	60							
85	27	29	31	32	34	36	38	40	42	44	46	49	51	53	56	58							
80	26	28	30	32	33	35	37	39	41	43	45	47	50	52	54	57	59						
75	26	27	29	31	33	34	36	38	40	42	44	46	48	50	53	55	57						
70	25	27	28	30	32	33	35	37	39	41	43	45	47	49	51	53	56	58					
65	24	26	27	29	31	32	34	36	38	40	42	43	45	47	50	52	54	56					
60	24	25	27	28	30	32	33	35	37	38	40	42	44	46	48	50	52	54	57				
55	23	24	26	27	29	31	32	34	36	37	39	41	43	45	46	48	50	52	55	57			
50	22	24	25	27	28	30	31	33	34	36	38	40	41	43	45	47	49	51	53	55	57		
45	22	23	24	26	27	28	30	32	33	35	37	38	40	42	43	45	47	49	51	53	55	57	
40			24	25	26	28	29	31	32	34	35	37	39	40	42	44	45	47	49	51	53	54	56
35				24	26	27	28	30	31	33	34	36	37	39	40	42	43	45	47	49	50	52	54
30							27	28	30	31	33	34	36	37	39	40	42	43	45	47	48	50	52
25										30	32	33	34	36	37	39	40	42	43	45	46	48	49
20																		40	41	43	44	45	47

LEGEND

HUMIDEX RANGE	DEGREE OF COMFORT
Less than 29	No discomfort
30 - 39	Some discomfort
40 - 45	Great discomfort; avoid exertion
Above 45	Dangerous
Above 54	Heat Stroke imminent

Source: Environment Canada: website <http://www.wul.qc.ec.gc.ca/meteo/documentation/Humidex/humidex_a.html>

Thermorégulation

Chaleur

<u>Mesures</u>

- **4 mesures environnementales liées a la température**

  Température de l'air (sec)

  Vitesse du vent

  Humidité

  Rayonnement

Thermorégulation

Chaleur

Mesures

- **Température apparente** « Température au thermomètre-globe mouillé »

  prend en compte l'effet de l'ensoleillement et du vent

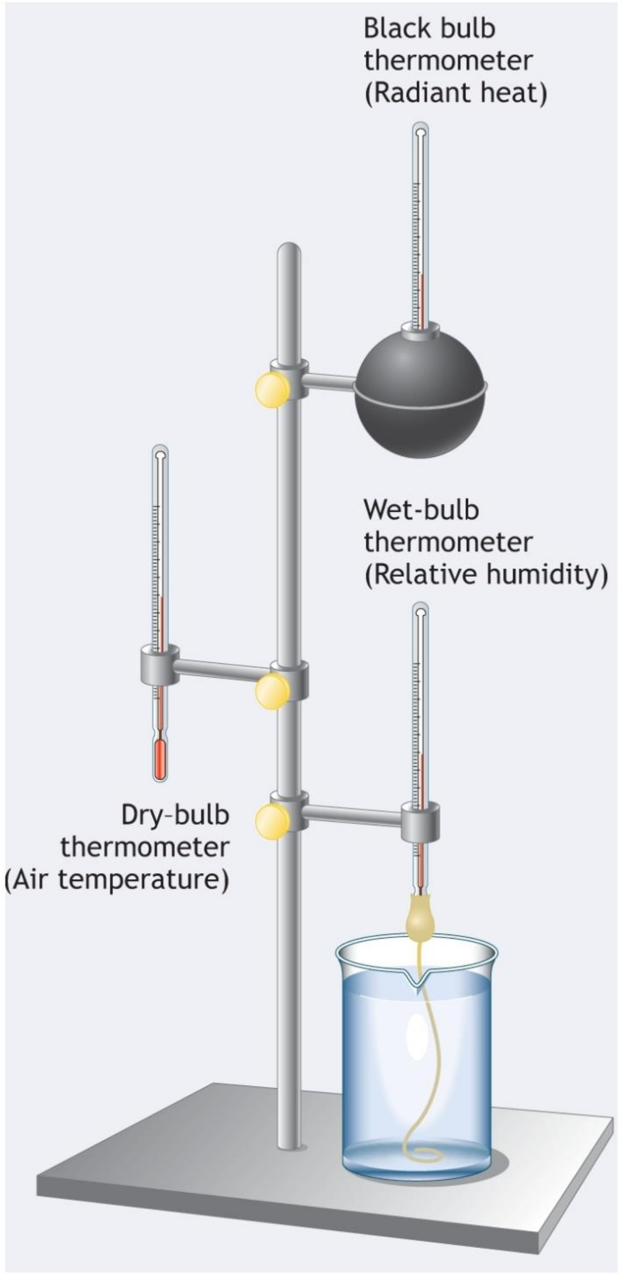
  T_w = Température humide (dans un tissu mouillé)

  T_g = Température rayonnante (thermomètre a globe noir)

  T_d = Température « sèche » (actuelle, bulbe sec)

  Wet Bulb Globe Temperature (US Marine Corps 1956)

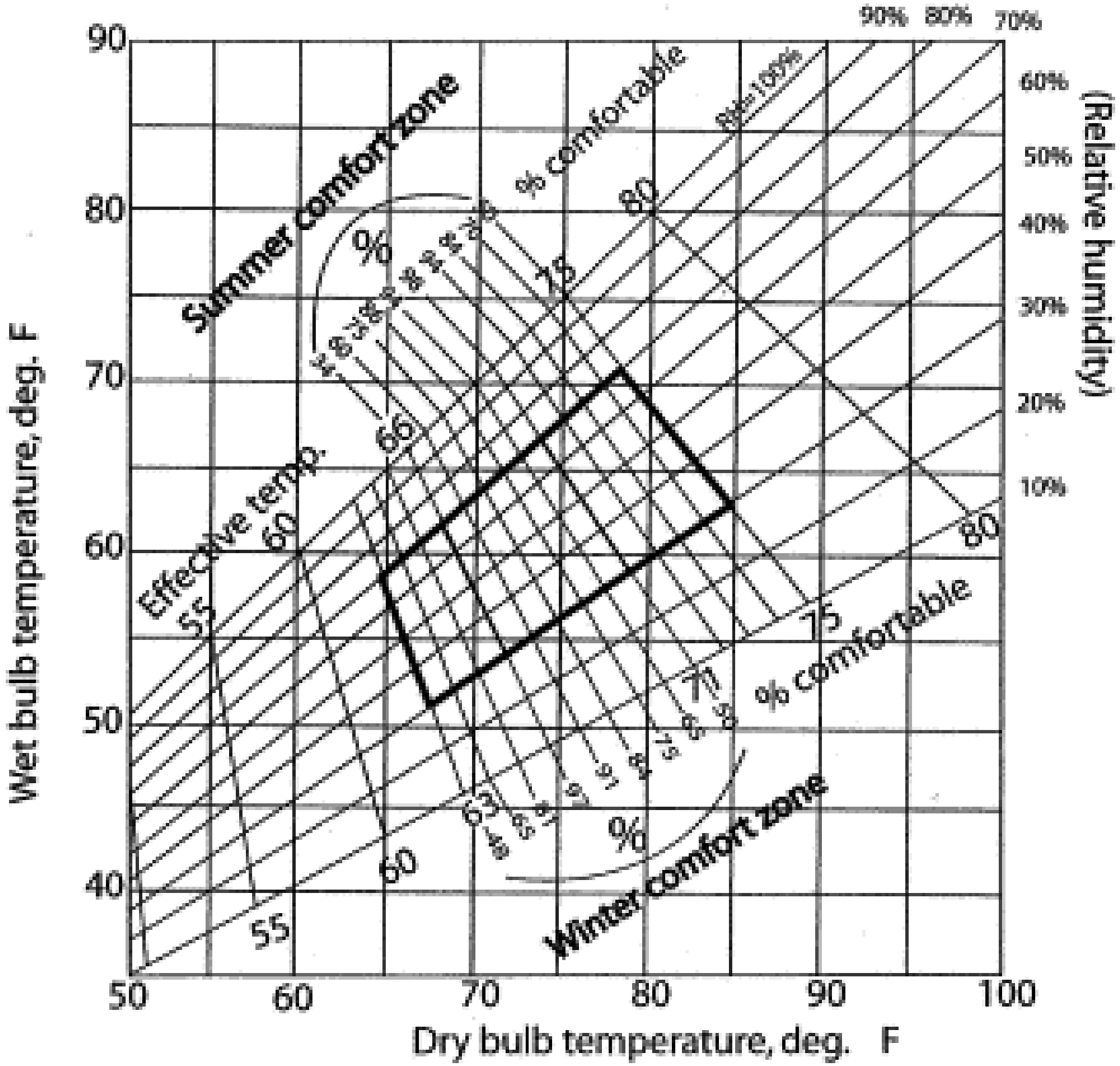
  $WBGT = 0.7\ T_w + 0.2\ T_g + 0.1\ T_f$

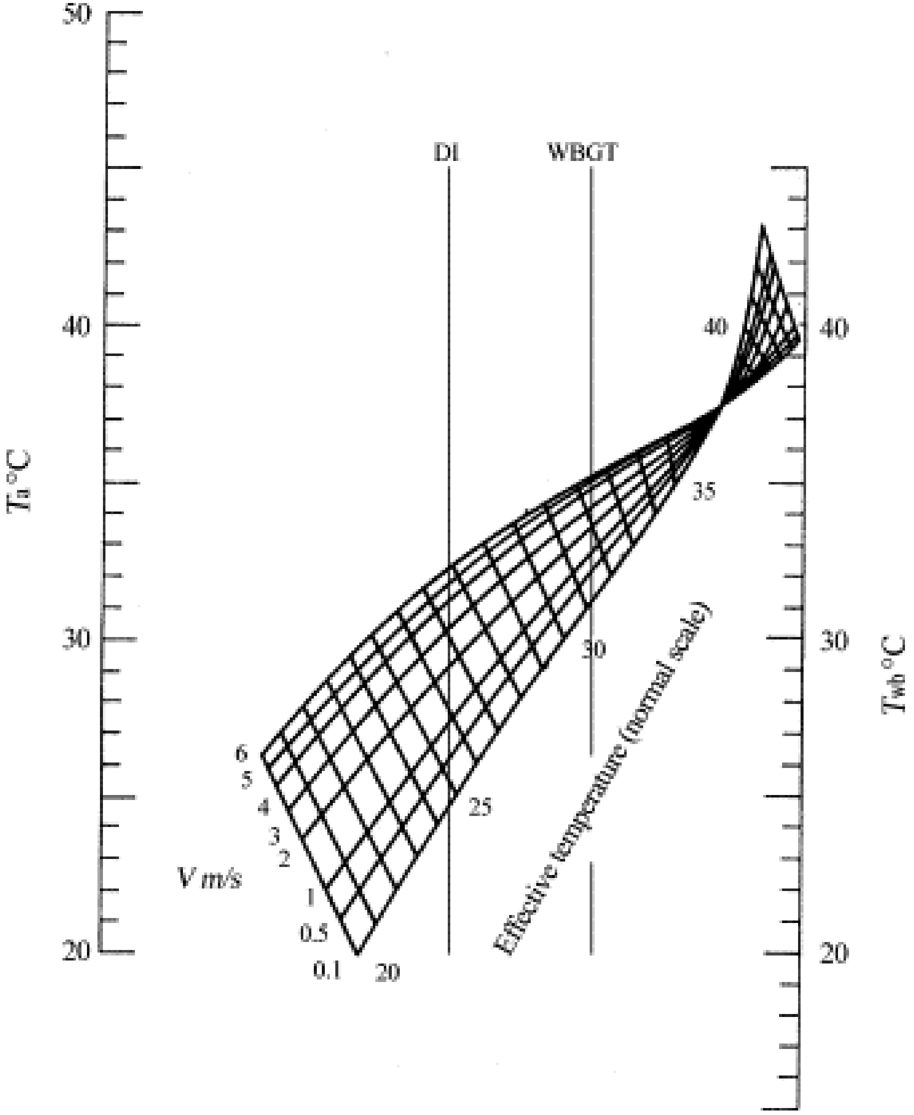


Abaques ± complexes

Chaleur

Mesures





Thermorégulation

Chaleur

Mesures

- **Température apparente** « Température au thermomètre-globe mouillé »

Catégorie	WBGT (°F)	WBGT (°C)	Drapeau	Activités physiques/travail
1	≤ 78–81.9	≤ 25.6–27.7	Blanc	Normales/Lourd
2	82–84.9	27.8–29.4	Vert	Normal avec 3 pauses de 3 min par heure
3	85–87.9	29.4–31.0	Jaune	Intensité basse avec 3 pauses de 3 min par heure
4	88–89.9	31.1–32.1	Rouge	Maximum 1h/travail léger
5	≥ 90	≥ 32.2	Noir	Pas d'activités/travail très léger

Répartition du travail dans un cycle travail/repos	**Acclimaté**				**Limite d'activité (non acclimaté)**			
	Léger	Modéré	Lourd	Très lourd	Léger	Modéré	Lourd	Très lourd
75 à 100 %	31,0	28,0	–	–	28,0	25,0	–	–
50 à 75 %	31,0	29,0	27,5	–	28,5	26,0	24,0	–
25 à 50 %	32,0	30,0	29,0	28,0	29,5	27,0	25,5	24,5
0 à 25 %	32,5	31,5	30,5	30,0	30,0	29,0	28,0	27,0

Thermorégulation

Chaleur

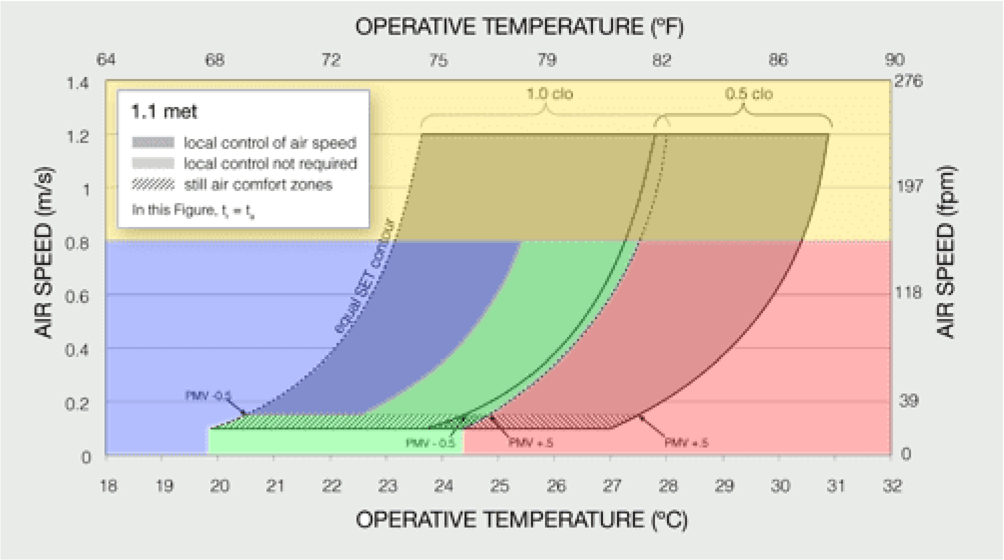
<u>Mesures</u>

- **Standard ASHRAE 55**

ASHRAE = American Society of Heating, Refrigerating and Air-conditioning Engineers

Système de normes établissant les zones de confort thermal en intérieur

Version la plus récente : 2017



Comfortable | Too Hot | Too Cold | Too Drafty

Thermorégulation

Chaleur

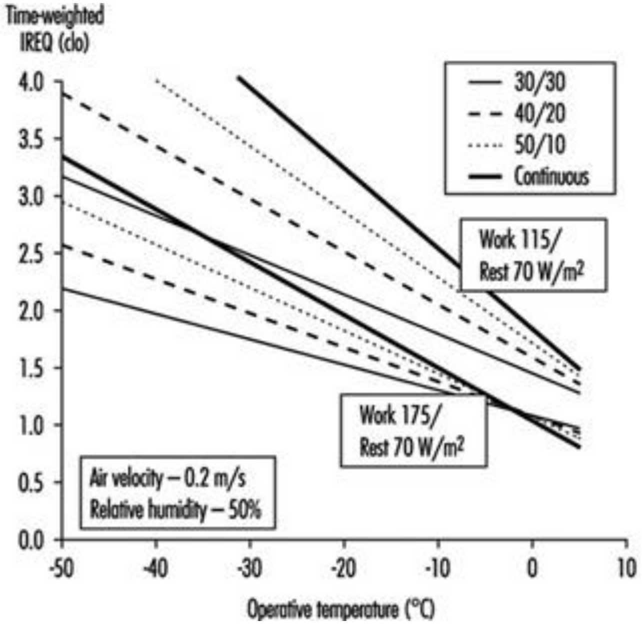
Mesures

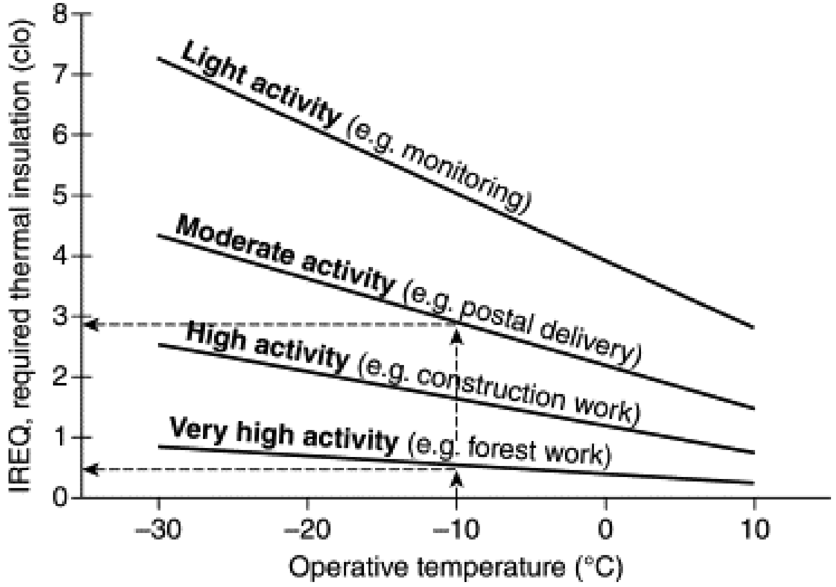
ASTM = American Society for Testing and Materials

- **Standard ASTM F2732-16**
- **ISO 11079**

Système de normes établissant l'efficacité de vêtements contre le froid

Unité = IREQ





http://www.eat.lth.se/fileadmin/eat/Termisk_miljoe/IREQ2009ver4_2.html

Gao C, Lin LY, Halder A, Kuklane K, Holmér I. Validation of standard ASTM F2732 and comparison with ISO 11079 with respect to comfort temperature ratings for cold protective clothing. Appl Ergon. 2015 Jan;46 Pt A:44-53. doi: 10.1016/j.apergo.2014.07.002. Epub 2014 Jul 17. PMID: 25042791.

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scandinavian Journal of Medicine and Science in Sports, 2010. 20(suppl. 3): p. 95-102

Effet du stress thermique sur la performance

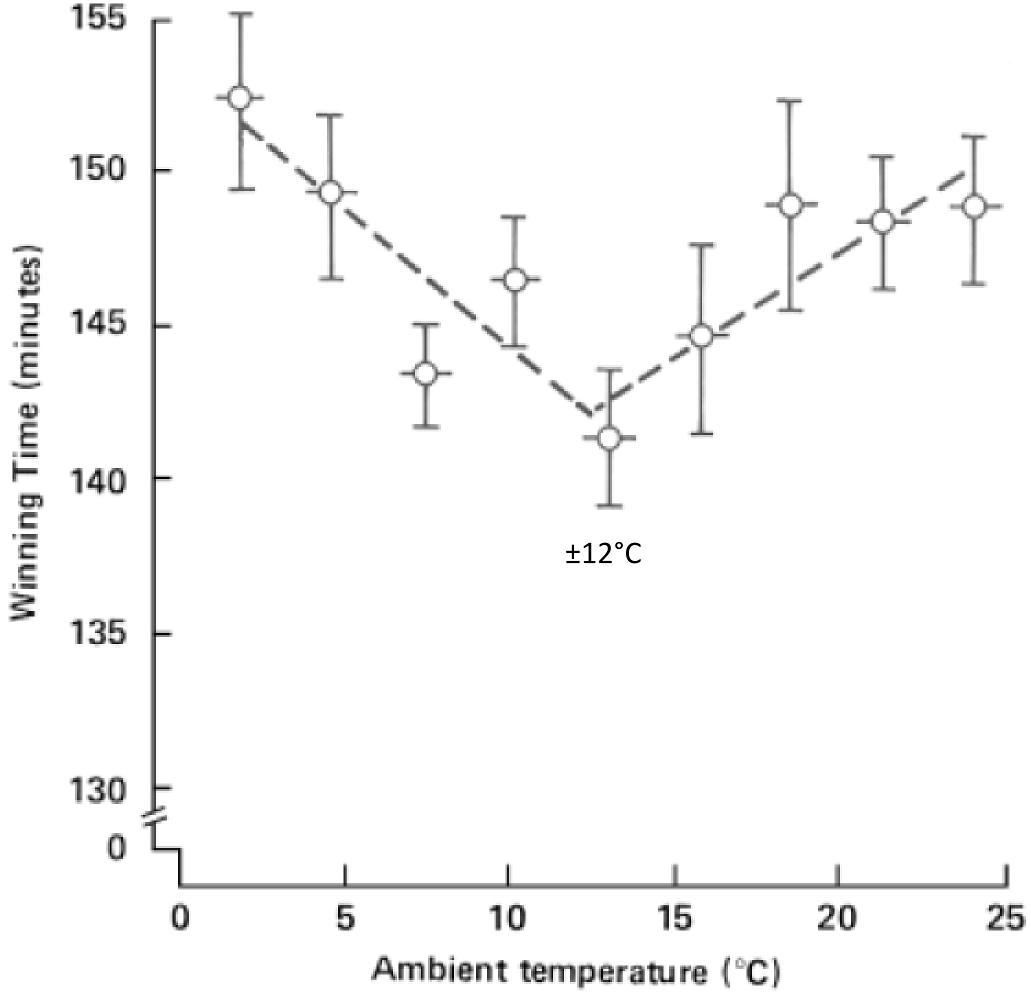


Fig. 1. Winning times at a series of marathon races in relation to ambient temperature. Redrawn from Frederick (1983).

Eliud Kipchoge

- Vienna 2019 : 9°C 1:59:41
- Monza 2018 : 12°C 2:00:25
- London 2019 : 14°C 2:02:37
- Berlin 2018 : 19°C 2:01:39
- London 2018 : 24°C 2:04:17
- Rio 2016 : 24°C 2:08:44

El Helou N, Tafflet M, Berthelot G, Tolaini J, Marc A, Guillaume M, Hausswirth C, Toussaint J-F. Impact of Environmental Parameters on Marathon Running Performance. PLOS ONE, 2012. 7(5)

Effet du stress thermique sur la performance

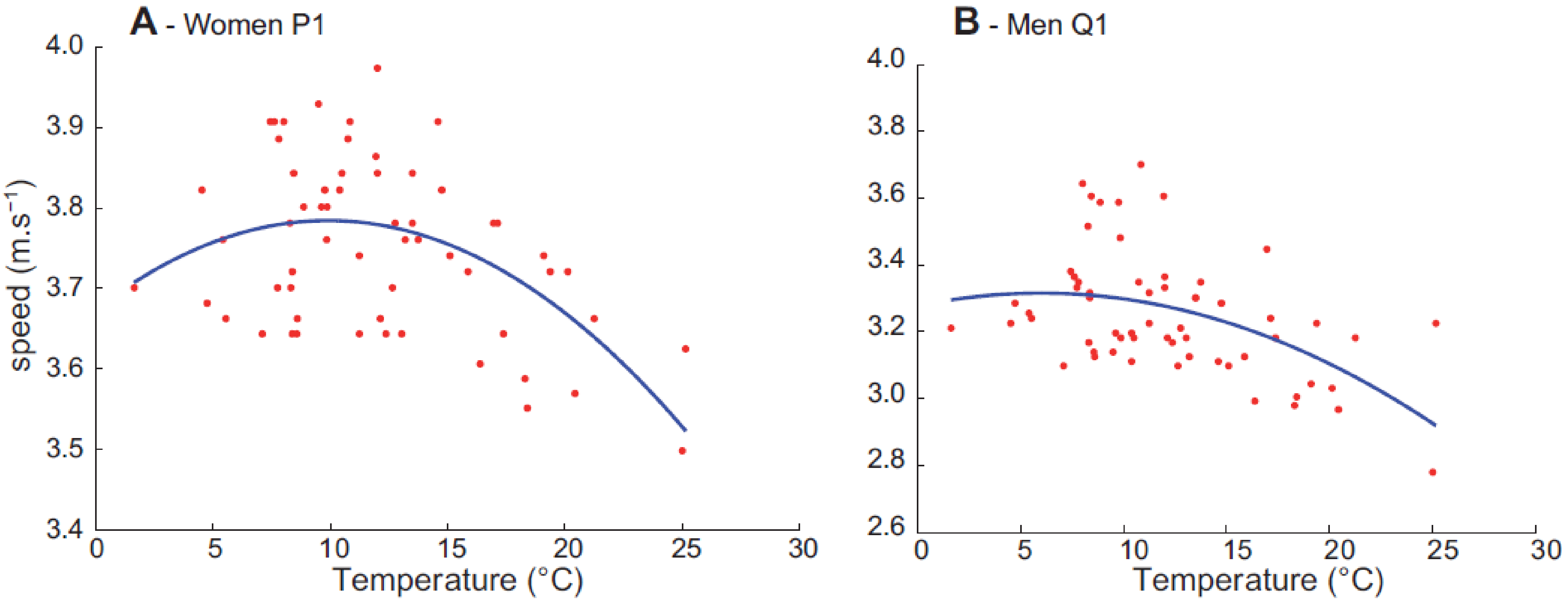


Figure 3. Quadratic second degree polynomial fit for Women's P1 running speeds vs. air temperature, $r^2 = 0.27$; $p < 0.001$; max = 9.9°C. B) Men's Q1 running speeds vs. air temperature, $r^2 = 0.24$; $p < 0.001$; max = 6°C.
doi:10.1371/journal.pone.0037407.g003

Cheuvront SN, Kenefick RW, Montain SJ, Sawka MN. *Mechanisms of aerobic performance impairment with heat stress and dehydration.* Journal of Applied Physiology, 2010. **109**(6): p. 1985-1995

Effet du stress thermique sur la performance

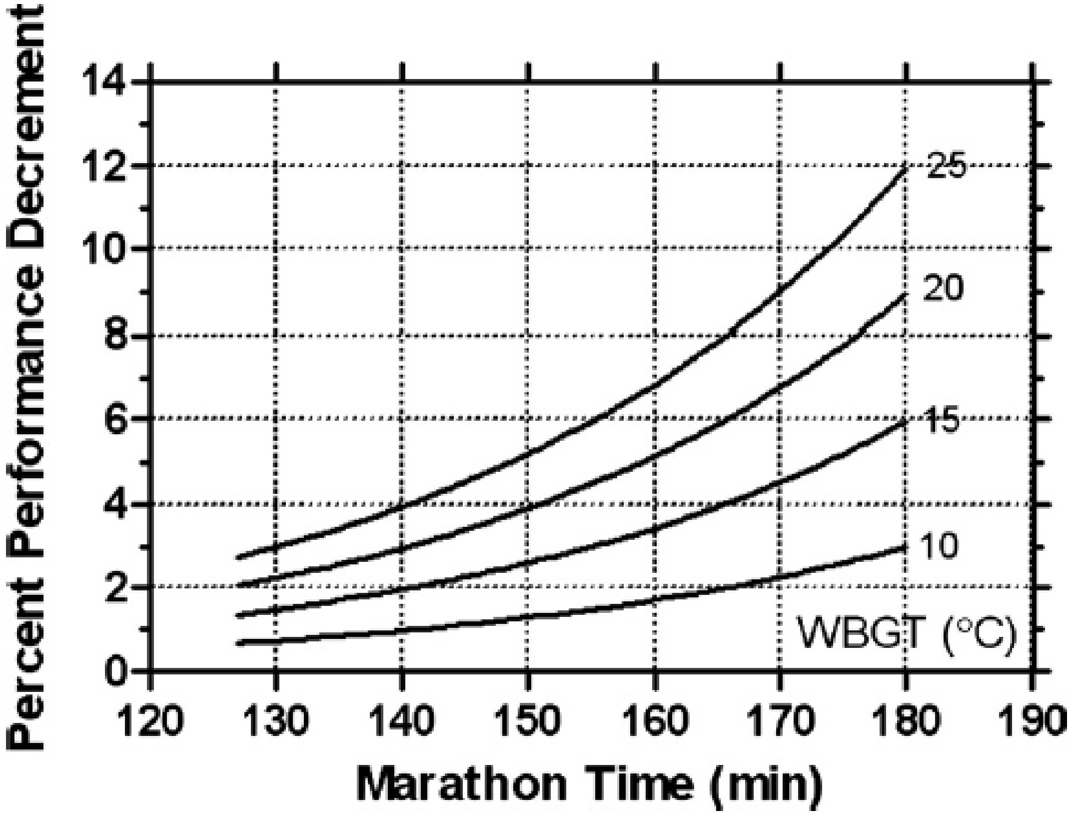
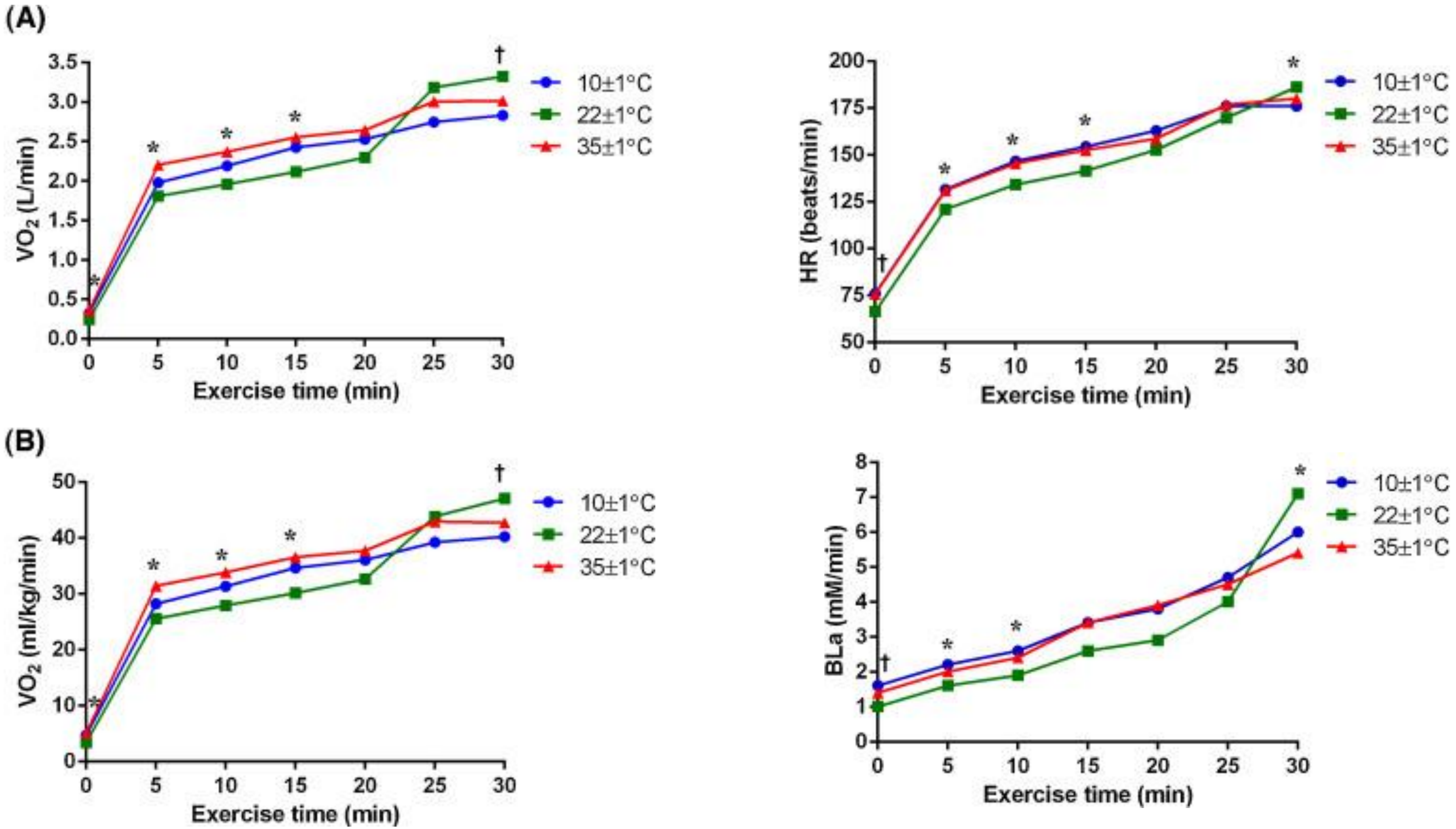


Fig. 1. Impact of weather on marathon running performance across a range of finishing times. As wet bulb globe temperature (WBGT) increases from 10 to 25°C [dry bulb temperature (T_{db}) = 8–22°C], elite competitors slow by ~2% (2–3 min), while 3-h finishers slow by almost 10% (18 min). WBGT, Reproduced from Ref. 23.

Thermorégulation

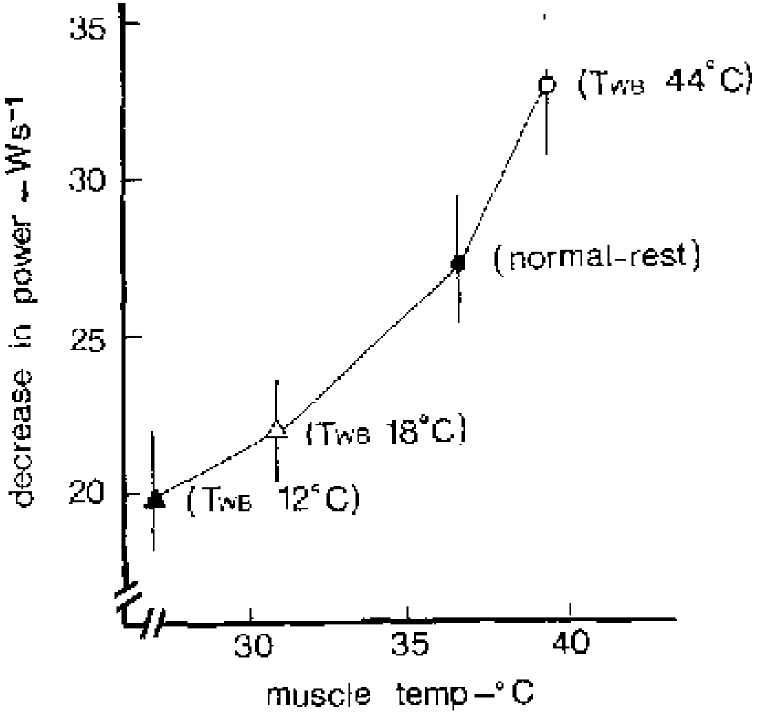
MiHyun No, Hyo-Bum Kwak, Effects of environmental temperature on physiological responses during submaximal and maximal exercises in soccer players, Integrative Medicine Research, Volume 5, Issue 3, 2016, Pages 216-222

Effet du stress thermique sur la physiologie

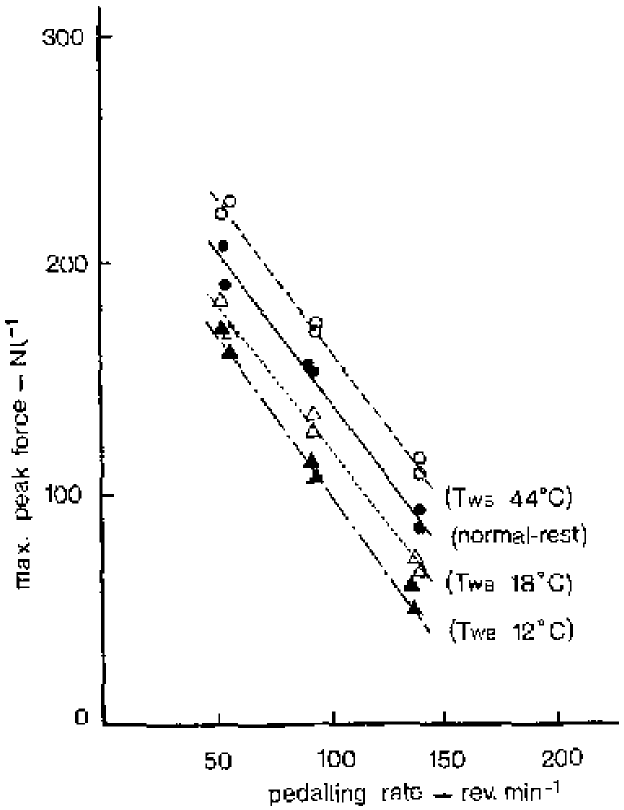


Sargeant, A.J. Effect of muscle temperature on leg extension force and short-term power output in humans. *Europ. J. Appl. Physiol.* **56,** 693–698 (1987)

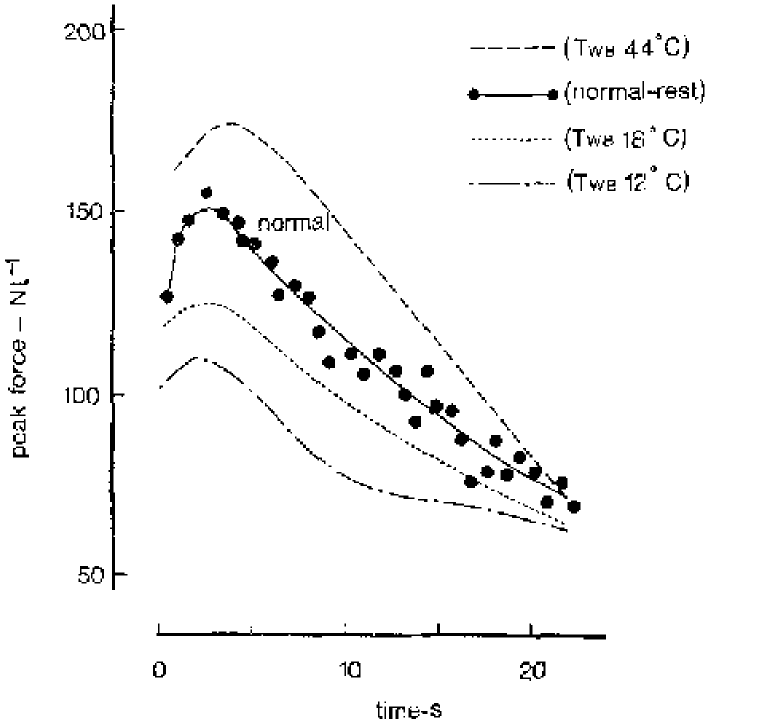
Effet du stress thermique sur la physiologie



Mean (+ S D) rate of decline in maximal peak power over 20 s exercise period in relation to muscle temperature (3 cm depth) for all 4 stlbjects pedalling at 95 rev



Relationship of maximal peak force (PFm,,,) to pedalling rate under the 4 conditions studied for 2 subjects. The calculated regression lines are shown for each condition and speed.



Changes in peak force during 20 s maximal effort for subject A pedalling at 95 rev m i n - ~. Peak force has been expressed in Newtons (N) and standardised for the upper leg muscle (plus bone)
volume

Thermorégulation
Froid

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Environnement frais ou légèrement froid habituellement bénéfique a la performance**

  Surtout pour les exercices d'endurance

  Intensité d'exercice élevée peut réduire le stress thermique

Froid - sec →

Weller AS, Millard CE, Stroud MA, Greenhaff PL, Macdonald IA. Physiological responses to cold stress during prolonged intermittent low- and high-intensity walking. Am J Physiol. 1997;272:R2025–33

Weller AS, Millard CE, Stroud MA, Greenhaff PL, Macdonald IA. Physiological responses to a cold, wet, and windy environment during prolonged intermittent walking. Am J Physiol. 1997;272:R226–33

Froid - humide →

Makinen TT, Gavhed D, Holmer I, Rintamäki H. Effects of metabolic rate on thermal responses at different air velocities in −10 °C. Comp Biochem Physiol. 2001;128:759–68

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Environnement frais ou légèrement froid habituellement bénéfique a la performance**

  Surtout pour les exercices d'endurance

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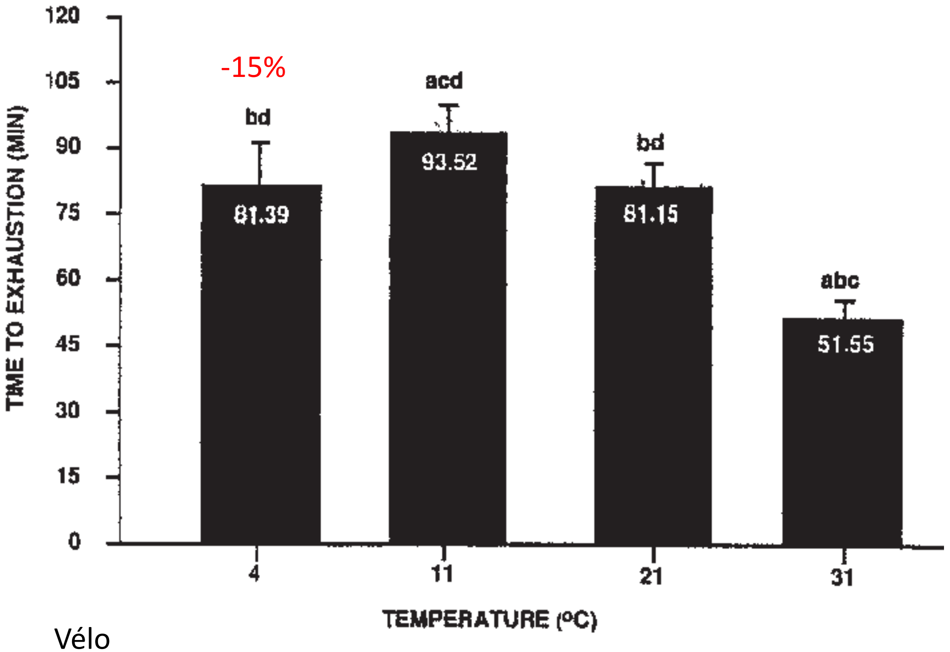
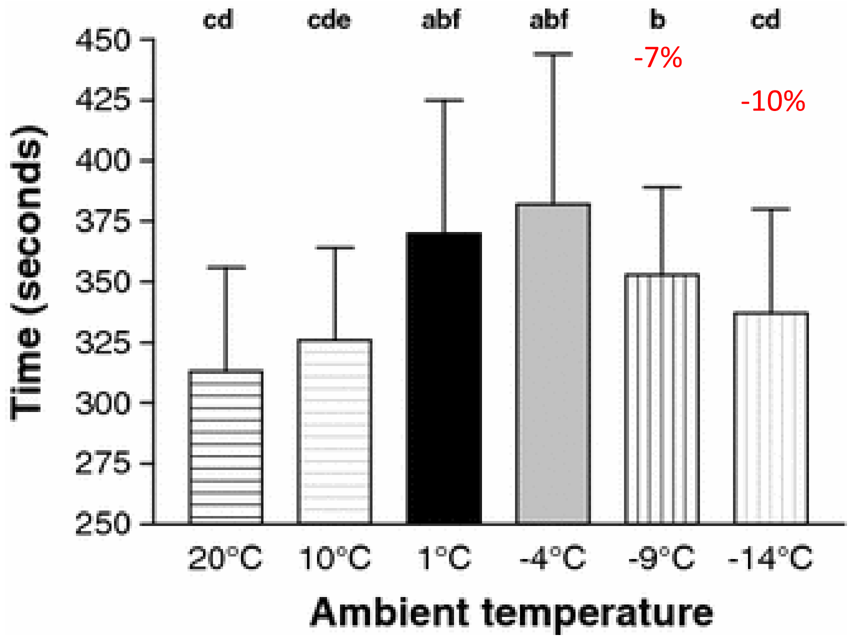


Vélo
Shorts et Tshirt
Tlim à 70% de PVO2max

Galloway and Maughan 1997



Tapis roulant
Habits de ski de fond + vent 5 m/s
Tlim

Sandsund et al 2012

Effects of mild whole body hypothermia on self-paced exercise performance
Steven A. H. Ferguson, Neil D. Eves, Brian D. Roy, Gary J. Hodges, and Stephen S. Cheung
Journal of Applied Physiology 2018 125:2, 479-485

Thermorégulation

Exposition au froid

Réponses physiologiques

15 km TT
- Neutre
- Froid
- Froid + hyperoxie

Froid = module la disponibilité d'O2

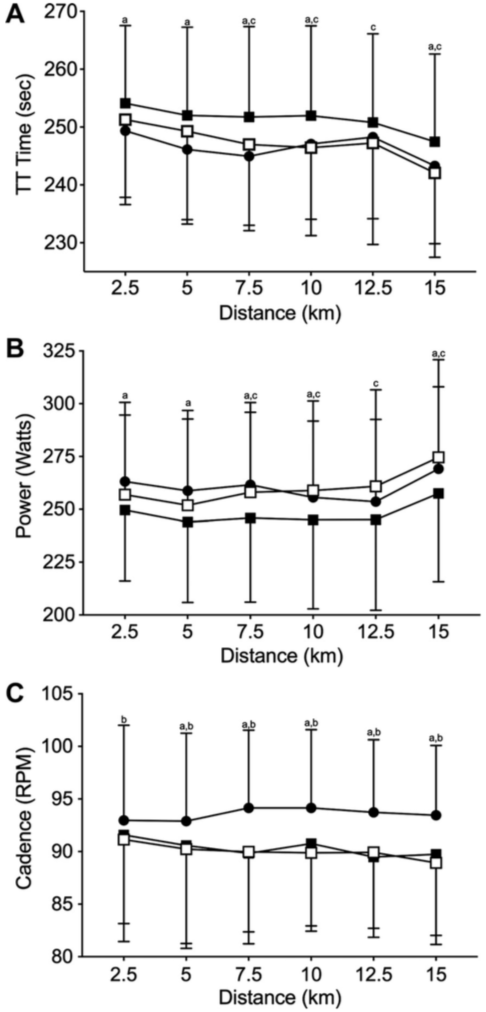


Fig. 2. Time trial (TT) time (*A*), power output (*B*), and cadence (*C*). Neutral (●), Cold (■), Cold+Hyper (□). [a]Neutral significantly different from Cold; [b]Neutral significantly different from Cold+Hyper; [c]Cold+Hyper significantly different from Cold.

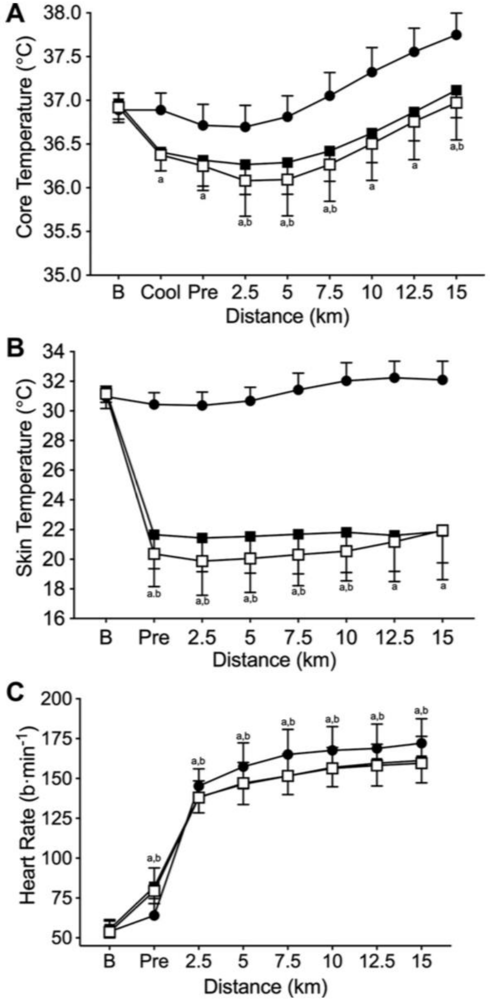


Fig. 1. Core temperature (*A*), mean skin temperature (*B*), and heart rate responses (*C*). Neutral (●), Cold (■), and Cold+Hyper (□). [a]Cold significantly different from Neutral; [b]Neutral significantly different from Cold+Hyper.

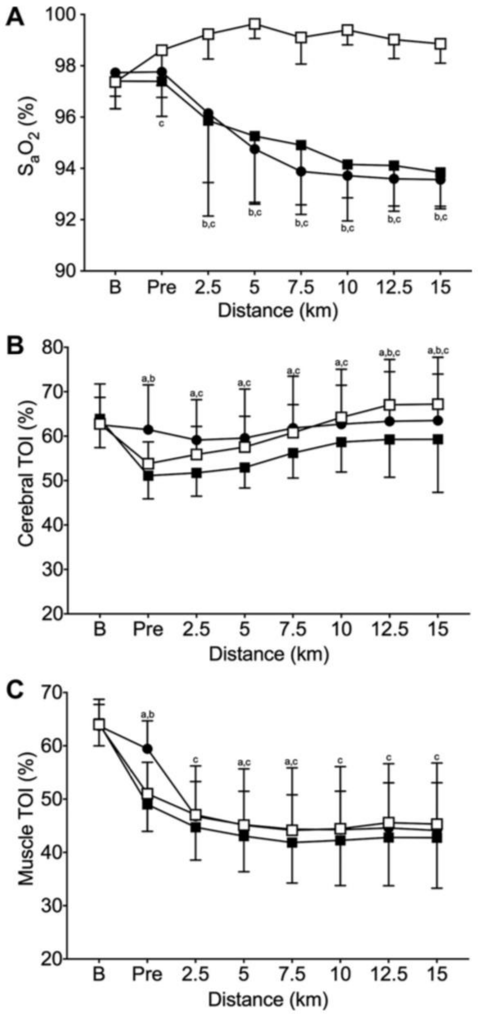


Fig. 3. Arterial oxygen saturation, (S_pO_2; *A*) and cerebral (*B*) and muscle tissue (*C*) oxygenation index responses. Neutral (●), Cold (■), Cold+Hyper (□). [a]Neutral significantly different from Cold; [b]Neutral significantly different from Cold+Hyper; [c]Cold+Hyper significantly different from Cold.

Thermorégulation

Exposition au froid

Réponses physiologiques

- **MAIS : le froid est délétère pour la fonction musculaire**

Refroidissement ambient entraîne potentiellement refroidissement du muscle et profond

Altérations du métabolisme aérobie

Réduction des diamètres vasculaires et donc de la perfusion

Transport et disponibilité de l'oxygène altéré

Altérations de puissance musculaire (moins de vitesse à une force donnée)

Baisse de viscosité

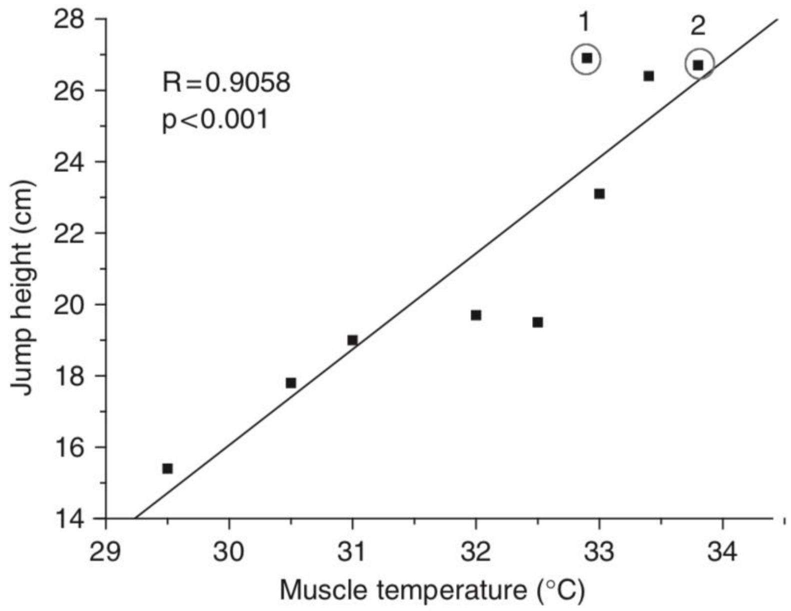


Fig. 1. Correlation between muscle temperature and jump height of the drop jump. Each point represents eight subjects except at 1, $n = 7$ and 2, $n = 3$. Modified with kind permission of Springer Science+Business Media from Oksa et al. (1997). Eur J Appl Physiol 75: 484–490 and Oksa et al. (1996a, b). Human Mov Sci 15: 591–603.

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Risque : Hypothermie**

  T° centrale < 35°C

  record (survivant) = 12°C

  plus courant qu'on ne le pense

  but = limiter les pertes de chaleur pour maintenir T° centrale

  mais attention à l'ensemble des conditions environnementales !

  ex. Marathon avec air $12°C_{WBG}$ + 75% humidité + 26 km/h vent
  4 coureurs < 37°C

  ex. Marathon avec air $19{,}8°C_{WBG}$ + pluie + 30 km/h vent
  28% des coureurs < 37°C
  1 coureur ~ 35°C

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Réponse initiale : augmentation de la dépense énergétique**

  dépense peut être 10-40% supérieure

  stratégies ± conscientes pour maintien de la température corporelle (centrale, extrémités)

  port de vêtements chauds, poids supplémentaire

  peut majorer sensation d'inconfort, de fatigue

  ± effort lié a la locomotion

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Réponse a l'hypothermie légère (32-35°C)**
  - vasoconstriction cutanée + horripilation
    - pour former une barrière isolante
    - mais réduit l'oxygénation tissulaire
  - augmentation des débits cardiaque et ventilatoire
    - FC augmente, P sanguine augmente
    - VE augmente
  - frissonnement
    - pour augmenter la production de chaleur (thermogenèse)
    - mais perturbateur, inconfortable, peu rentable sur le long terme
  - Apathie, amnésie, troubles du jugement
    - réduction de la dépense énergétique

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Réponse a l'hypothermie modérée (28-32°C)**

vasoconstriction cutanée + horripilation *peau glacée, cyanosée*

pour former une barrière isolante

mais réduit l'oxygénation tissulaire

diminution des débits cardiaque et ventilatoire *encombrement bronchique*

FC ralentit, fibrillation possible, P sanguine imprenable

VE diminue

frissonnement

pour augmenter la production de chaleur (thermogenèse)

mais perturbateur, inconfortable, peu rentable sur le long terme

Apathie, amnésie, troubles du jugement *coma possible*

réduction de la dépense énergétique

dilatation des pupilles, altération des reflexes

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Réponse a l'hypothermie sévère (<28°C)**

vasoconstriction cutanée + horripilation — *peau glacée, cyanosée*

pour former une barrière isolante

mais réduit l'oxygénation tissulaire

diminution des débits cardiaque et ventilatoire — *risque d'arrêt cardiaque*

FC ralentit, fibrillation imminente, P sanguine imprenable

VE diminue

frissonnement

pour augmenter la production de chaleur (thermogenèse)

mais perturbateur, inconfortable, peu rentable sur le long terme

Apathie, amnésie, troubles du jugement — *coma*

réduction de la dépense énergétique

dilatation des pupilles, altération des reflexes

La mort ne peut être déclarée qu'après réchauffement en milieu hospitalier

Thermorégulation

Exposition au froid

Réponses physiologiques

- **Gelures notamment aux extrémités**

  tissus sous-perfusés = gèlent rapidement

  = brulure par le froid

  = tissu gèle : liquides gèlent => destruction de la cellule (œdèmes, risque de thrombose)

  = ischémie secondaire due a la vasoconstriction

  derme > tissu adipeux > muscles > os

  entraine une nécrose si non traitées

Thermorégulation

Exposition au froid

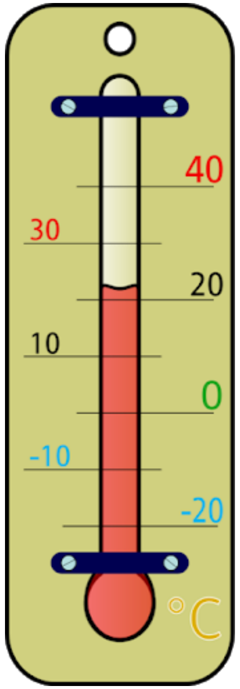
Dextérité

Température du tissue organique

<28°C = réduction de la force, puissance, endurance

<24°C = réduction de la mobilité articulaire

<20°C = réduction de la vitesse de conduction nerveuse



Température des doigts

<15°C = altération de dextérité manuelle

<8°C = perte de sensation tactile

MAIS les gants décroissent la dextérité de 60 à 70%, donc pas toujours adapté

Thermorégulation

Exposition au froid

<u>Dextérité</u>

- **Nombreuses applications**

Thermorégulation

Castellani JW, Spitz MG, Karis AJ, Martini S, Young AJ, Margolis LM, Phillip Karl J, Murphy NE, Xu X, Montain SJ, Bohn JA, Teien HK, Stenberg PH, Gundersen Y, Pasiakos SM. Cardiovascular and thermal strain during 3–4 days of a metabolically demanding cold-weather military operation. Extreme Physiology & Medicine, 2017. 6(1): p. 2

Exposition au froid

Températures négatives

Castellani et al. Extrem Physiol Med (2017) 6:2
DOI 10.1186/s13728-017-0056-6

Extreme Physiology & Medicine

RESEARCH Open Access

Cardiovascular and thermal strain during 3–4 days of a metabolically demanding cold-weather military operation

John W. Castellani[1*], Marissa G. Spitz[1], Anthony J. Karis[1], Svein Martini[2], Andrew J. Young[1], Lee M. Margolis[1], J. Phillip Karl[1], Nancy E. Murphy[1], Xiaojiang Xu[1], Scott J. Montain[1], Jamie A. Bohn[1], Hilde K. Teien[2], Pål H. Stenberg[3], Yngvar Gundersen[2] and Stefan M. Pasiakos[1]

Background: Cardiovascular (CV) and thermal responses to metabolically demanding multi-day military operations in extreme cold-weather environments are not well described. Characterization of these operations will provide greater insights into possible performance capabilities and cold injury risk.

Methods: Soldiers from two cold-weather field training exercises (FTX) were studied during 3-day (study 1, $n = 18$, age: 20 ± 1 year, height: 182 ± 7 cm, mass: 82 ± 9 kg) and 4-day (study 2, $n = 10$, age: 20 ± 1 year, height: 182 ± 6 cm, mass: 80.7 ± 8.3 kg) ski marches in the Arctic. Ambient temperature ranged from −18 to −4 °C during both studies. Total daily energy expenditure (TDEE, from doubly labeled water), heart rate (HR), deep body (T_{pill}), and torso (T_{torso}) skin temperature (obtained in studies 1 and 2) as well as finger (T_{fing}), toe (T_{toe}), wrist, and calf temperatures (study 2) were measured.

Table 1 Energy expenditure, intake, and balance during study iterations #1 and #2

	Energy expenditure	Energy intake	Energy balance
Study 1 ($n = 17$)	6821 ± 578 (28.5 ± 2.4)	3465 ± 622 (14.5 ± 2.6)	−3357 ± 691 (−14.0 ± 2.9)
Study 2 ($n = 9$)	6394 ± 544 (26.8 ± 2.3)	2714 ± 799 (11.4 ± 3.3)	−3782 ± 1001 (−15.8 ± 4.2)

Values (mean ± S.D.) are in kcals and MJ (parenthetically)

Weather data were obtained from the closest meteorological station to each training exercise by accessing the Norwegian Meteorological Institute website (http://eklima.met.no). In study 1, air temperatures ranged from −18 to −6 °C; wind speeds ranged from 5 to 13 m s^{-1}; in study 2, air temperatures ranged from −17 to −3 °C and wind speeds ranged from 0.3 to 19 m s^{-1}. These environmental conditions produced wind chill temperature index values as low as −26 °C in study 1 and −25 °C in study 2.

Thermorégulation

Castellani JW, Spitz MG, Karis AJ, Martini S, Young AJ, Margolis LM, Phillip Karl J, Murphy NE, Xu X, Montain SJ, Bohn JA, Teien HK, Stenberg PH, Gundersen Y, Pasiakos SM. Cardiovascular and thermal strain during 3–4 days of a metabolically demanding cold-weather military operation. Extreme Physiology & Medicine, 2017. 6(1): p. 2

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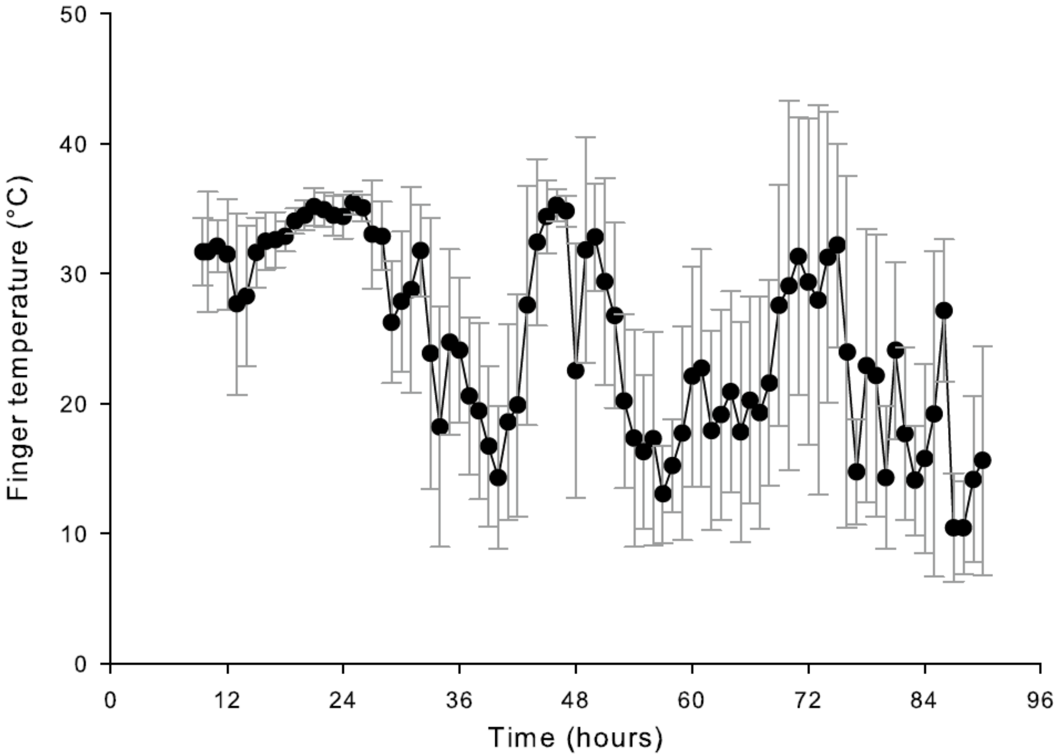
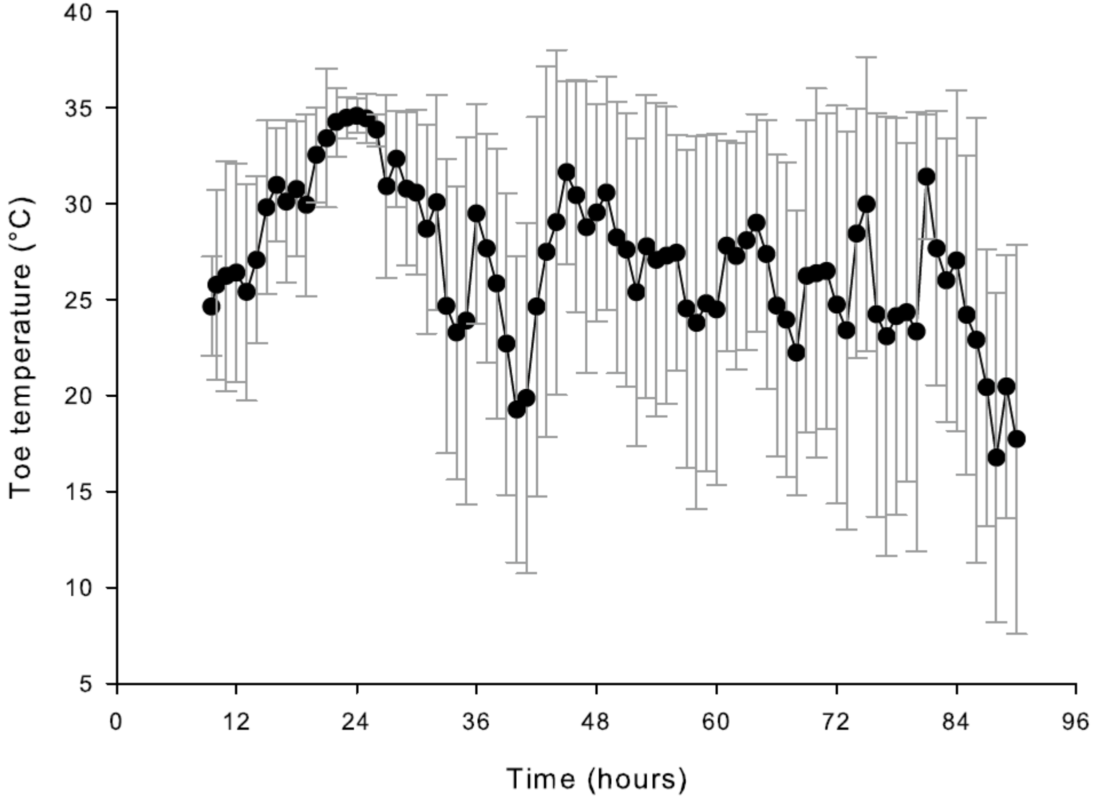
Températures négatives





Thermorégulation

Castellani JW, Spitz MG, Karis AJ, Martini S, Young AJ, Margolis LM, Phillip Karl J, Murphy NE, Xu X, Montain SJ, Bohn JA, Teien HK, Stenberg PH, Gundersen Y, Pasiakos SM. Cardiovascular and thermal strain during 3–4 days of a metabolically demanding cold-weather military operation. Extreme Physiology & Medicine, 2017. 6(1): p. 2

Exposition au froid

<u>Températures négatives</u>


Castellani *et al. Extrem Physiol Med* (2017) 6:2
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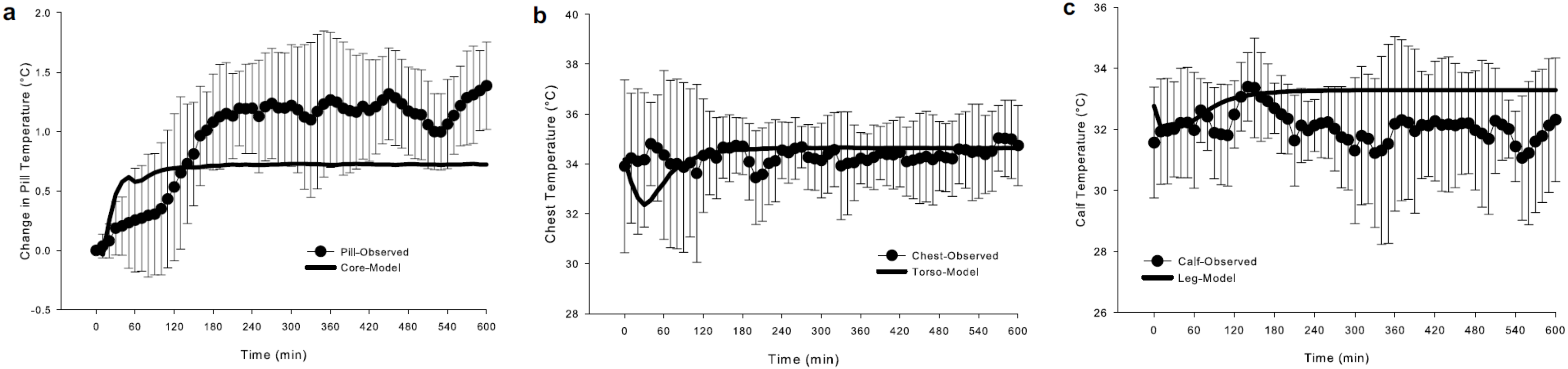

Thermorégulation

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Results: TDEE was 6821 ± 578 kcal day^{-1} and 6394 ± 544 for study 1 and study 2, respectively. Mean HR ranged from 120 to 140 bpm and mean T_{pill} ranged between 37.5 and 38.0 °C during skiing in both studies. At rest, mean T_{pill} ranged from 36.0 to 36.5 °C, (lowest value recorded was 35.5 °C). Mean T_{fing} ranged from 32 to 35 °C during exercise and dropped to 15 °C during rest, with some T_{fing} values as low as 6–10 °C. T_{toe} was above 30 °C during skiing but dropped to 15–20 °C during rest.

Conclusions: Daily energy expenditures were among the highest observed for a military training exercise, with moderate exercise intensity levels (~65% age-predicted maximal HR) observed. The short-term cold-weather training did not elicit high CV and T_{pill} strain. T_{fing} and T_{toe} were also well maintained while skiing, but decreased to values associated with thermal discomfort at rest.

Keywords: Deep body temperature, Finger temperature, Heart rate, IREQ, Thermal modeling

Thermorégulation

Žákovská A, Knechtle B, Chlíbková D, Miličková M, Rosemann T, and Nikolaidis PT. The Effect of a 100-km Ultra-Marathon under Freezing Conditions on Selected Immunological and Hematological Parameters. Frontiers in Physiology 8: 2017.

Exposition au froid

Températures négatives

frontiers in Physiology

ORIGINAL RESEARCH
published: 12 September 2017
doi: 10.3389/fphys.2017.00638

Check for updates

The Effect of a 100-km Ultra-Marathon under Freezing Conditions on Selected Immunological and Hematological Parameters

Alena Žákovská[1], Beat Knechtle[2], Daniela Chlíbková[3], Marie Miličková[1], Thomas Rosemann[2] and Pantelis T. Nikolaidis[4]*

[1] Department of Animal Physiology and Immunology, Research Centre for Toxic Compounds in the Environment, Institute of Experimental Biology, Faculty of Science, Masaryk University, Brno, Czechia, [2] Institute of Primary Care, University of Zurich, Zurich, Switzerland, [3] Centre of Sports Activities, Brno University of Technology, Brno, Czechia, [4] Exercise Physiology Laboratory, Nikaia, Greece

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Exposition au froid

Températures négatives

TABLE 1 | Table 1 Race performance of the subjects.

Athlete	Running pace (min/km)	Overall time (h:min:s)	Completed distance (km)
1	4:26	7:23:15	100
2	6:01	6:07:40	61
3	7:03	8:23:42	71,5
4	5:26	9:04:01	100
5	7:05	11:40:47	100
6	5:42	9:29:18	100
7	6:59	11:38:24	100
8	6:17	10:28:21	100
9	7:50	12:03:55	92.5
10	9:18	10:22:58	67
11	4:37	7:41:54	100
12	6:23	10:38:47	100
13	5:50	9:43:21	100
14	7:08	11:51:47	100
15	5:49	9:41:48	100

TABLE 2 | Comparison of immunological, hematological, and biochemical parameters before and after the race (Mean ± *SD* and % change) without statistically significant changes.

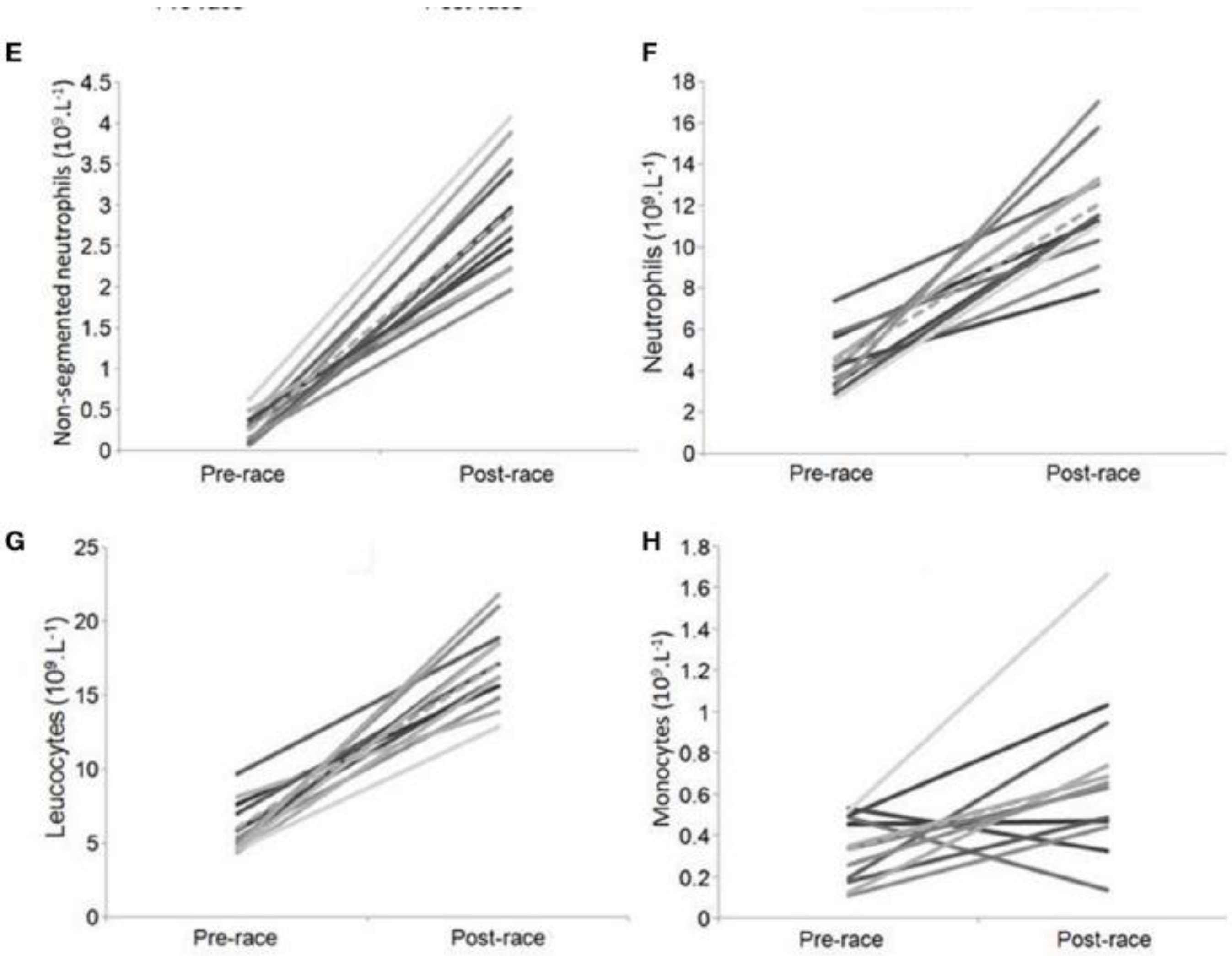
Parameter	Before the race	After the race	% change
Red blood cells ($10^{12} \cdot l^{-1}$)	4.84 (0.31)a	4.81 (0.32)a	−0.62
Hematocrit	0.43 (0.02)a	0.42 (0.02)a	−0.94
Hemoglobin ($g \cdot dl^{-1}$)	135.27 (15.72)a	133.43 (16.57)a	−1.36
Alanine aminotransferase ($U \cdot l^{-1}$)	8.91 (4,17)c	8.39 (5.17)c	−5.84
Lymphocytes ($10^{9} \cdot l^{-1}$)	1.40 (0.28)a	1.41 (0.46)a	0.71
Eosinophils ($10^{9} \cdot l^{-1}$)	0.12 (0.17)a	0.04 (0.08)a	−66.67
Basophils ($10^{9} \cdot l^{-1}$)	0	0	0.00
Immunoglobulin A ($mg \cdot dl^{-1}$)	21.09 (90.52)c	24.0 (13.56)c	13.80
Immunoglobulin M ($mg \cdot dl^{-1}$1)	24.72 (136.15)c	24.78 (137.00)c	0.24

Number of participants (after the race, bad statue of some of the respondents resulted in problems with blood intake for hematological analysis): a (12); b (14); c (15); % change—percentage change of variables (the difference between pre- and post-quantity)

Žákovská A, Knechtle B, Chlíbková D, Miličková M, Rosemann T, and Nikolaidis PT. The Effect of a 100-km Ultra-Marathon under Freezing Conditions on Selected Immunological and Hematological Parameters. Frontiers in Physiology 8: 2017.

Exposition au froid

Températures négatives



The main findings were that (i) after the race, leukocytes increased and in seven of 15 athletes the number of leucocytes doubled; (ii) immature neutrophils, mature neutrophils and monocytes increased, whereas the number of lymphocytes and eosinophils did not change; (iii) IgG increased, but IgA and IgM remained unchanged; (iv) platelets increased, whereas the number of red blood cells, hematocrit and hemoglobin did not change; and (v) LDH and CK values increased, but ALT concentration did not change.

In summary, a wide range of physiological changes in athletes occurred after a 100-km ultra-marathon under cold conditions. We concluded that prolonged endurance running had a negative effect on the immune system expressed as inflammation. Moreover, it could affect physiological functions of the body which could exhibit elevated susceptibility to the development of infection. Long exposure to cold weather along with the length and severity of the race, our respondents' athletic preparation

Thermorégulation

Noakes TD. The Limits of Human Endurance: What is the Greatest Endurance Performance of All Time? Which Factors Regulate Performance at Extreme Altitude? 2007. Boston, MA: Springer US

Exposition au froid

Réponses physiologiques

- **Globalement : peu de problème avec de l'exercice**

Epreuves	dépense approx.		
TV	1500 kcal/jour		
Alpinisme de haute altitude	4 000 kcal/jour		
Yiannis Kouros Sydney-Melbourne '87	56 000 kcal		*5j 20h ((1060 km, 9328 kcal/j)*
Courses de 6 jours	60 000 kcal		*6 jours*
6 jours	168 000 kcal		*6 jours*
Tour de France	180 000 kcal		*21 jours (~8 000 kcal/j)*
Race Across America	340 000 kcal		*10 jours*
Traversée Pole Sud 1911-12 (Amundsen)	500 000 kcal	pour les chiens	*97 jours*
Traversée Pole Sud 1911-12 (Scott)	1 000 000 kcal		*10h/j, pendant 159 jours (2500 km)*

Thermorégulation

John W. Castellani, Andrew J. Young, Human physiological responses to cold exposure: Acute responses and acclimatization to prolonged exposure, Autonomic Neuroscience, Volume 196, 2016, Pages 63-74

Exposition au froid

Réponses physiologiques

- **Acclimatation au froid ?**

- Possible
- Amélioration des capacités de thermorégulation
- Surtout sur critères perceptuels (habituation)
- Mais aussi des adaptations physiques
  - Ajustements métaboliques (thermogénèse)
  - Isolation thermique
  - Facteurs de transcription favorisant la thermogénèse et la vasoconstriction
- Recommandations variables : 6h/h dans un air à 15°C pdt 31 j, 8h/j dans un air à 12°C pdt 10 j
- Immersion dans l'eau froide : semble favoriser les adaptations de vasoconstriction

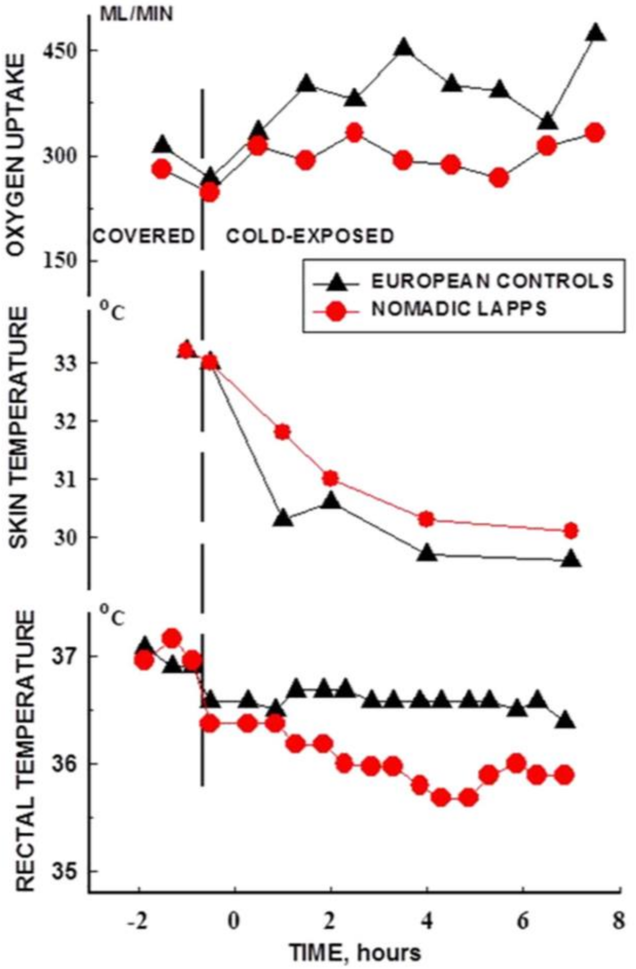


Fig. 5. Oxygen uptake, and skin and rectal temperature responses during an overnight cold exposure (0 °C) between Norwegain Saami and European controls. Data demonstrate a cold habituation response, i.e., thermal effector responses are blunted (lower metabolic heat production, less vasoconstriction) in the indigenous circumpolar residents. Drawn from data reported by Andersen et al. (Andersen et al., 1960).

Thermorégulation
Chaud

Thermorégulation

Exposition au chaud

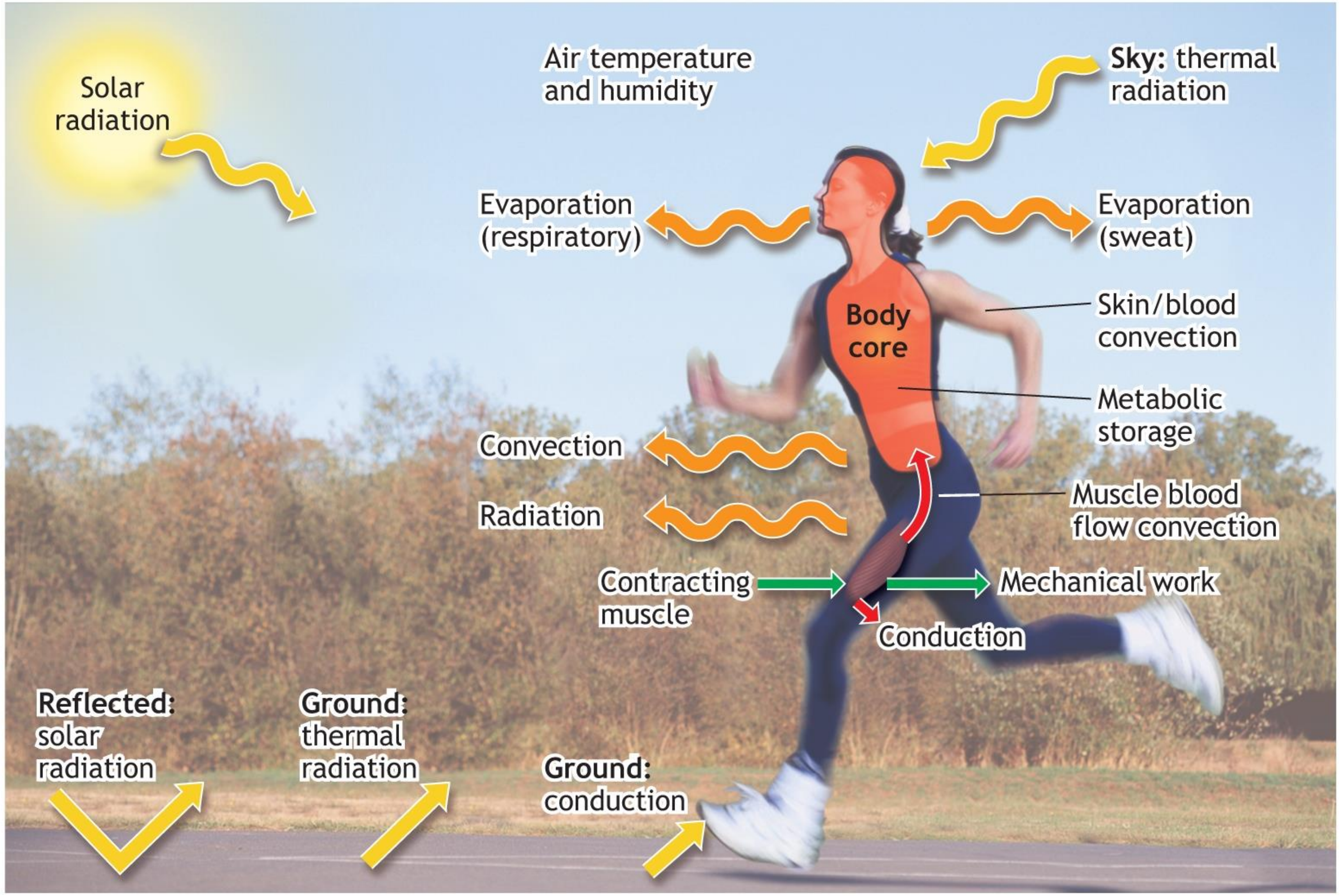
Au repos, T° cutanée ~ 33°C

Si environnement > 33°C

- pas de perte d'énergie par convection
- les tissus gardent la chaleur

Dépend surtout de la transpiration

sudation ~ 1500 kcal/h



Thermorégulation

Exposition au chaud

Variabilité

- **Vent**

Décroit la T° perçue

Permet un transfert d'énergie par convection plus grand

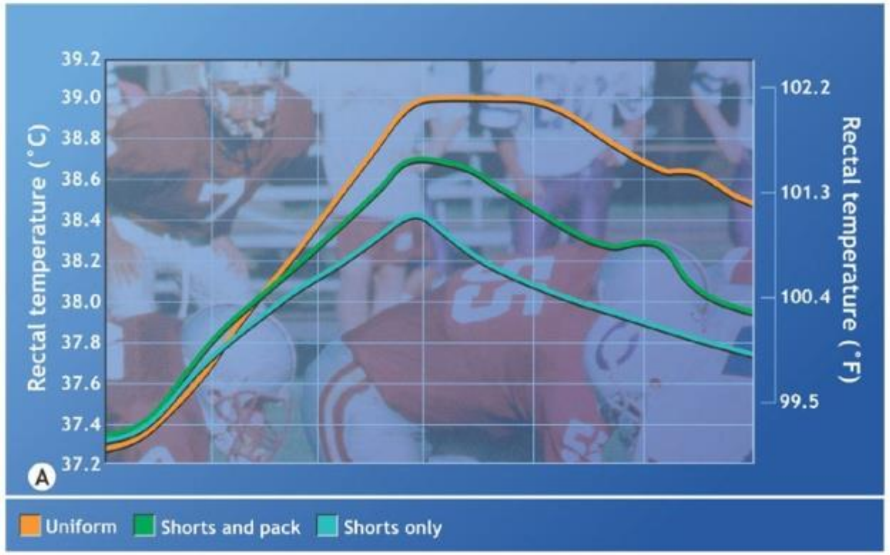
Cyclisme, course : génère une vitesse effective

marche moins bien par vent de dos…

Vêtements : couche isolante

absorbe/transfert la sueur

décroit le rayonnement



Corbett J, White DK, Barwood MJ, Wagstaff CRD, Tipton MJ, McMorris T, Costello JT. The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat. Sports Med, 2017

Exposition au chaud

Variabilité

- **Effet de compétition**

Sports Med
DOI 10.1007/s40279-017-0816-x

ORIGINAL RESEARCH ARTICLE

The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat

Jo Corbett[1] · Danny K. White[1] · Martin J. Barwood[2] · Christopher R. D. Wagstaff[1] · Michael J. Tipton[1] · Terry McMorris[1,3] · Joseph T. Costello[1]

Prolonged exercise (≥ 30 min) is impaired in hot environments (air temperature ≥ 30 °C) compared with cooler conditions (air temperature ≤ 20 °C) [1], although the effect of ambient temperature on prolonged exercise performance is not dichotomous, but is instead a continuum, with the fastest performances often achieved at a temperature of ~ 10 °C and an exponential slowing occurring as temperature increases beyond this optimum [2, 3]. Early studies using fixed-intensity, time-to-exhaustion models emphasised the role of a 'critical' (~ 40 °C) core temperature (T_C) in the aetiology of fatigue in the heat [4].

In laboratory studies in the heat, participants typically exercise alone, yet, as has been noted [8], the T_C recorded in competitive, non-laboratory situations often exceeds that typical during self-paced laboratory trials [1]. Indeed, 'competition' has been cited as a risk factor for exertional heat illness [8, 12]. Although laboratory evidence for this assertion is limited, heat-related collapse in athletic competition is well documented in the field [13, 14]. Laboratory studies in cooler environments have shown improved 2000-m cycling performance when athletes believed they were competing against another participant in a simulated race, but were actually competing against an avatar of their own solo performance [15]. Similarly, participants who believed they were 'racing' against a previous 4000-m cycling time trial (TT), but were actually racing against an avatar with a 2% higher power, matched the superior performance [16]. If pacing is a thermoregulatory behaviour, it is important to understand the effect of competition on pacing, performance and thermoregulation during exercise in hot conditions.

Thermorégulation

Corbett J, White DK, Barwood MJ, Wagstaff CRD, Tipton MJ, McMorris T, Costello JT. The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat. Sports Med, 2017

Exposition au chaud

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CrossMark

ORIGINAL RESEARCH ARTICLE

The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat

Jo Corbett[1] · Danny K. White[1] · Martin J. Barwood[2] · Christopher R. D. Wagstaff[1] · Michael J. Tipton[1] · Terry McMorris[1,3] · Joseph T. Costello[1]

Variabilité

- **Effet de compétition**

first attendance they completed questionnaires to measure trait-like psychological characteristics before undertaking an incremental exercise test, followed 30 min later by a 20-km familiarisation solo cycling TT on a computer-generated 'virtual' racecourse, in cool [target wet-bulb globe temperature (WBGT) 12 °C (target dry bulb temperature (T_{db}) 15 °C; target relative humidity (RH) 55%)] conditions. On the second attendance they undertook a further preliminary solo 20-km TT in cool conditions. On the three subsequent attendances, participants undertook the experimental trials (balanced crossover order), consisting of (i) 20-km solo TT, cool conditions (CoolSolo); (ii) 20-km solo TT, hot [target WBGT 26 °C (target T_{db} 30 °C; target RH 55%)] conditions (HotSolo); (iii) 20-km head-to-head competition, hot conditions (HotH2H). The HotH2H trial included a deception element, described subsequently in Sect. 2.3.4. A WBGT of 12 °C is classed as a cool environment; a WBGT of 26 °C is moderately hot with a high risk of exertion heat illness for unacclimated individuals undertaking continuous activity [10].

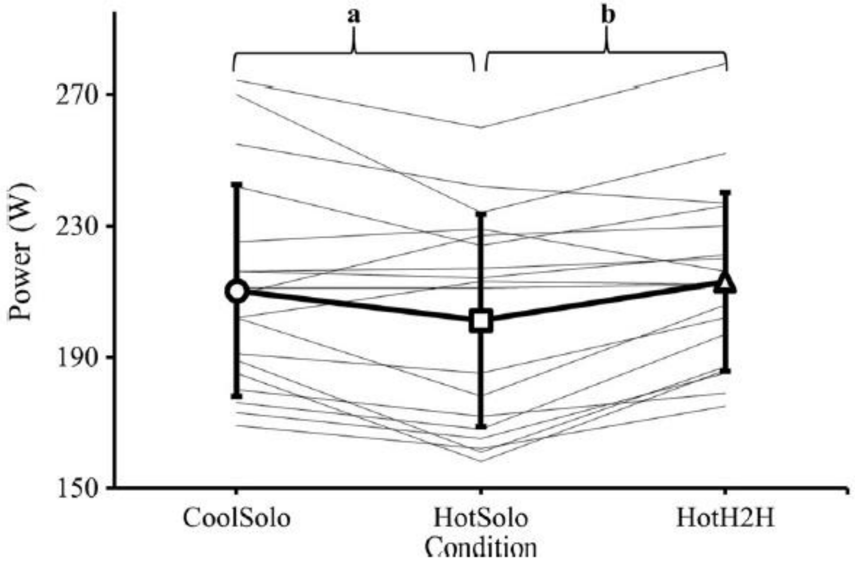

Fig. 1 Mean (SD) [thick black line ($n = 18$)] and individual (thin black lines) average power outputs for 20-km time trials in cool (CoolSolo) and hot (HotSolo) environments, and a 20-km simulated head-to-head competition in a hot environment (HotH2H). **a** Significant difference ($p < 0.05$) between CoolSolo and HotSolo; **b** significant difference ($p < 0.01$) between HotSolo and HotH2H

Thermorégulation

Corbett J, White DK, Barwood MJ, Wagstaff CRD, Tipton MJ, McMorris T, Costello JT. The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat. Sports Med, 2017

Exposition au chaud

Variabilité

- **Effet de compétition**

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ORIGINAL RESEARCH ARTICLE

The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat

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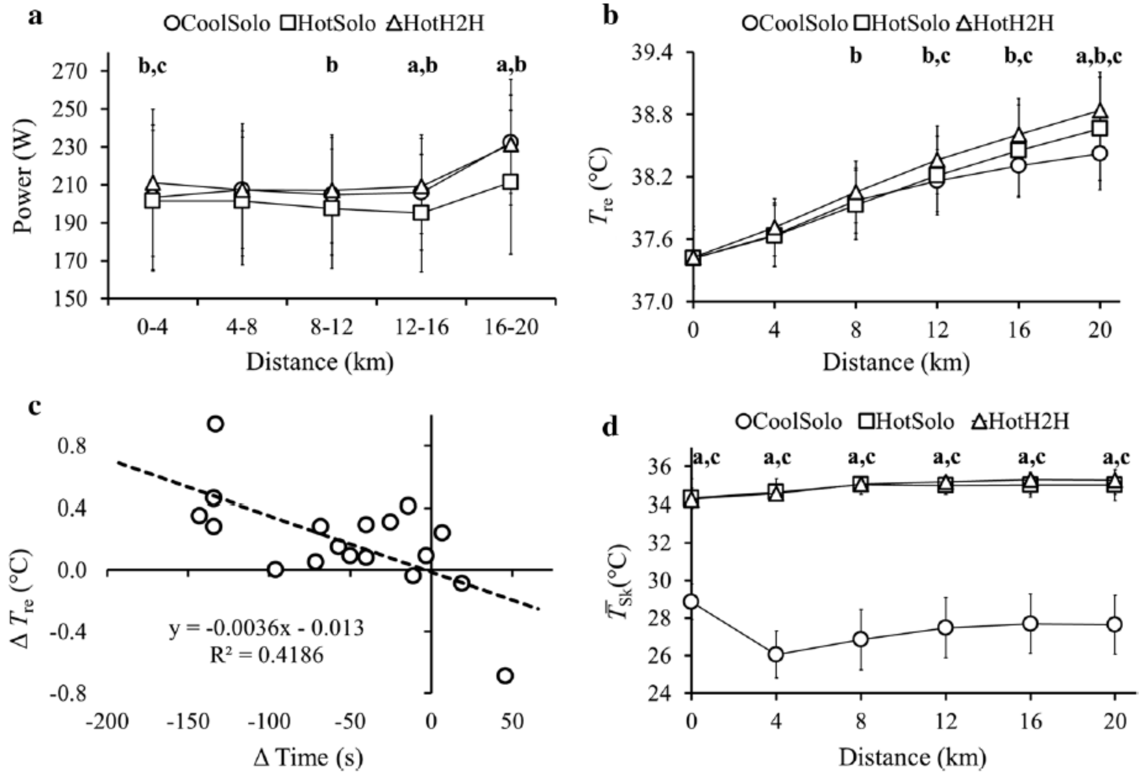


Fig. 2 **a** Mean (SD) pacing profile for 4-km segments for 20-km time trials in cool (CoolSolo) and hot (HotSolo) environments, and a 20-km simulated head-to-head competition in a hot environment (HotH2H). **b** Mean (SD) rectal temperature (T_{re}) at 4-km intervals for CoolSolo, HotSolo and HotH2H. **c** Relationship between individual Δ time in HotH2H vs HotSolo and individual Δ end-exercise T_{re} in HotH2H vs HotSolo. **d** Mean (SD) mean skin temperature ($\overline{T}_{sk}$) at 4-km intervals for CoolSolo, HotSolo and HotH2H. **a** significant difference ($p < 0.05$) between CoolSolo and HotSolo; **b** significant difference ($p < 0.05$) between HotSolo and HotH2H; **c** significant difference ($p < 0.05$) between CoolSolo vs HotH2H

Compared with solo exercise in the heat, head-to-head competition in a hot environment alters behavioural thermoregulation (i.e. pacing), resulting in faster performances. Consequently, metabolic heat production and thermophysiological strain are increased, but this is not reflected in perceptual measures. These novel data are consistent with the hypothesis that competition is a risk factor for heat illness. We suggest that this effect may result from neurochemical changes due to a psychophysiological stress response or motivational effects, whereas reduced internal focus might alter the relationship between *perceived* and *actual* thermophysiological state. Finally, individuals with a propensity for DRT, or high levels of resilience, may be more sensitive to the effects of competition, indicating that certain trait-like characteristics might help identify those at increased risk of heat illness.

Thermorégulation

Exposition au chaud

Bruce Fordyce (1955 -)

9x vainqueur des Comrades
Ancien recordman du monde du 100 km

Comrades = 89 km en ~5,5 hr (5:27:18)

16,3 km/h
~ 20 000 kJ
~ 61 kJ/min

~ 6 000 kJ pour le transport
~ 14 000 kJ perdues en chaleur

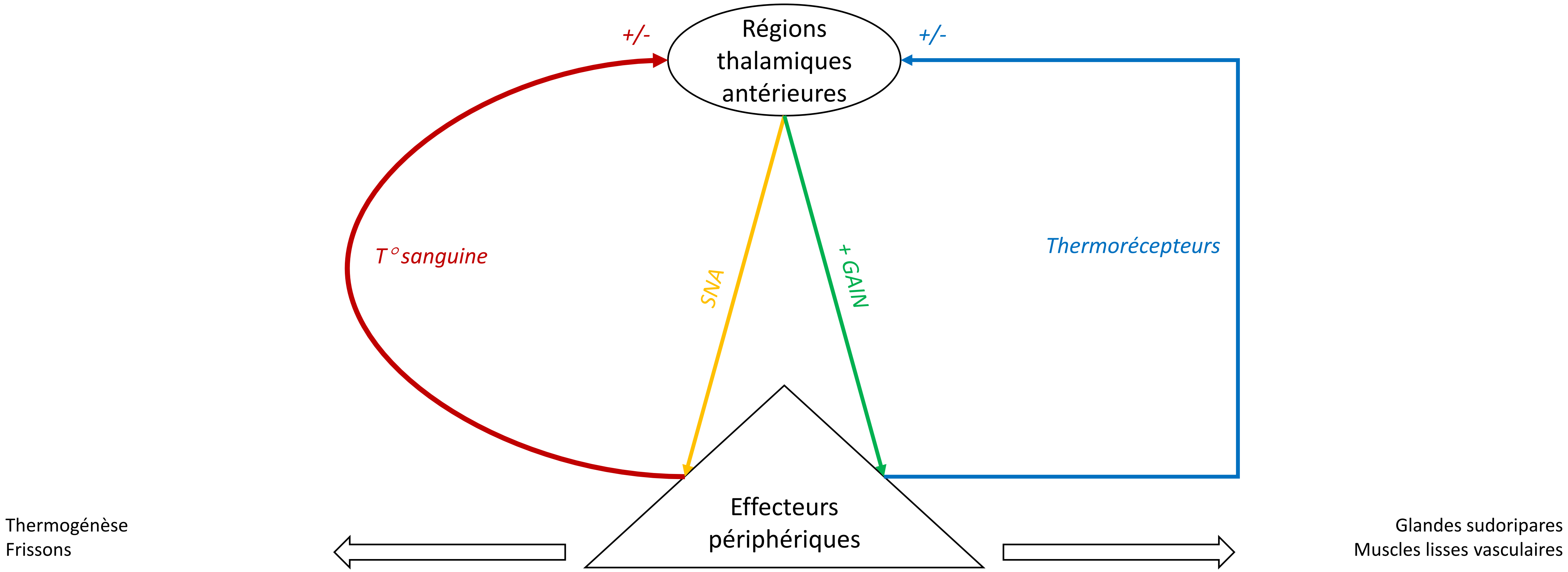
majorité à perdre pour prévenir le coup de chaud (>43°C)

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Contrôle hypothalamique**



Thermorégulation

Exposition au chaud

Réponse physiologique

- **Activation du système nerveux sympathique**

  Débit cardiaque — $FC \times VS = Q_C$

  Ajustements vasculaire — vasodilatation périphérique + constriction splanchnique

  Régulation de la pression artérielle

- **± Activité musculaire**

  réchauffe le sang

  en fonction des thermorécepteurs cutanés et centraux — *~ individuel ~ fitness*

  - si froid — *effet vasoconstricteur sur derme*
  - si chaud — *effet vasodilatateur sur derme (jusqu'à 8 L/min)*

Thermorégulation

Exposition au chaud

Réponse physiologique

Limitation !
La plupart des études réalisées avec T° sèche

- **Activation du système nerveux sympathique**

  Débit cardiaque — FC x VS = Q_C

  Ajustements vasculaire — vasodilatation périphérique + constriction splanchnique

  Régulation de la pression artérielle

- **± Activité musculaire**

  réchauffe le sang

  en fonction des thermorécepteurs cutanés et centraux — *~ individuel ~ fitness*

  - si froid *effet vasoconstricteur sur derme*
  - si chaud *effet vasodilatateur sur derme (jusqu'à 8 L/min)*

Pathophysiologie = Diabète T2, Maladie de Raynaud, Erythromélalgie } Altération du reflexe vasodilatateur cutané

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Réponses hormonales**

Aldostérone

Hormone stéroïdienne produite par le cortex adrénergique

Action sur les tubes distaux du néphron

Contribue a conserver H_2O et NA^+

Vasopressine

Hormone neuro-hypophysaire

Action sur le tube collecteur du néphron

Augmente la réabsorption d'H_2O

Thermorégulation

Hargreaves M. Physiological limits to exercise performance in the heat. Journal of Science and Medicine in Sport, 2008. 11: p. 66-71.

Journal of Science and Medicine in Sport (2008) 11, 66–71

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Journal of Science and Medicine in Sport

www.elsevier.com/locate/jsams

REVIEW

Physiological limits to exercise performance in the heat

Mark Hargreaves

Department of Physiology, The University of Melbourne, VIC 3010, Australia

Exposition au chaud

Réponse physiologique

- **Augmentation du métabolisme des glucides**

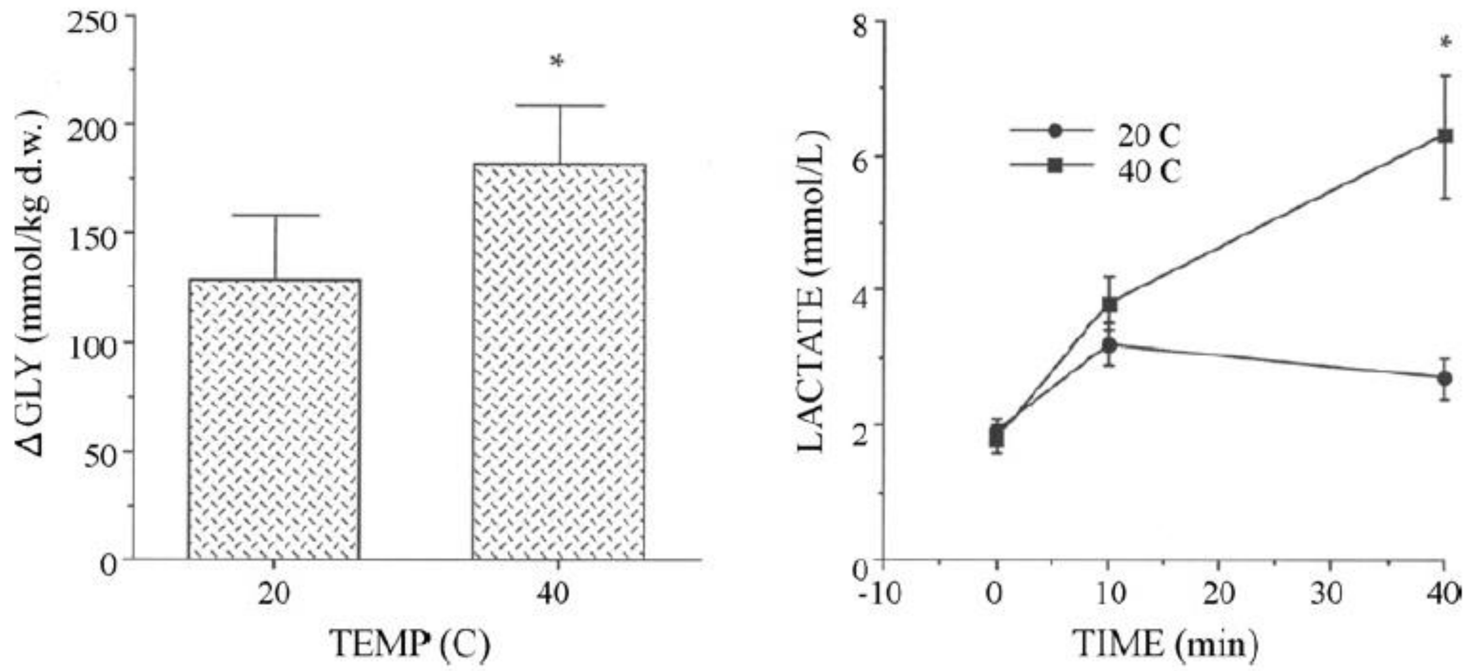


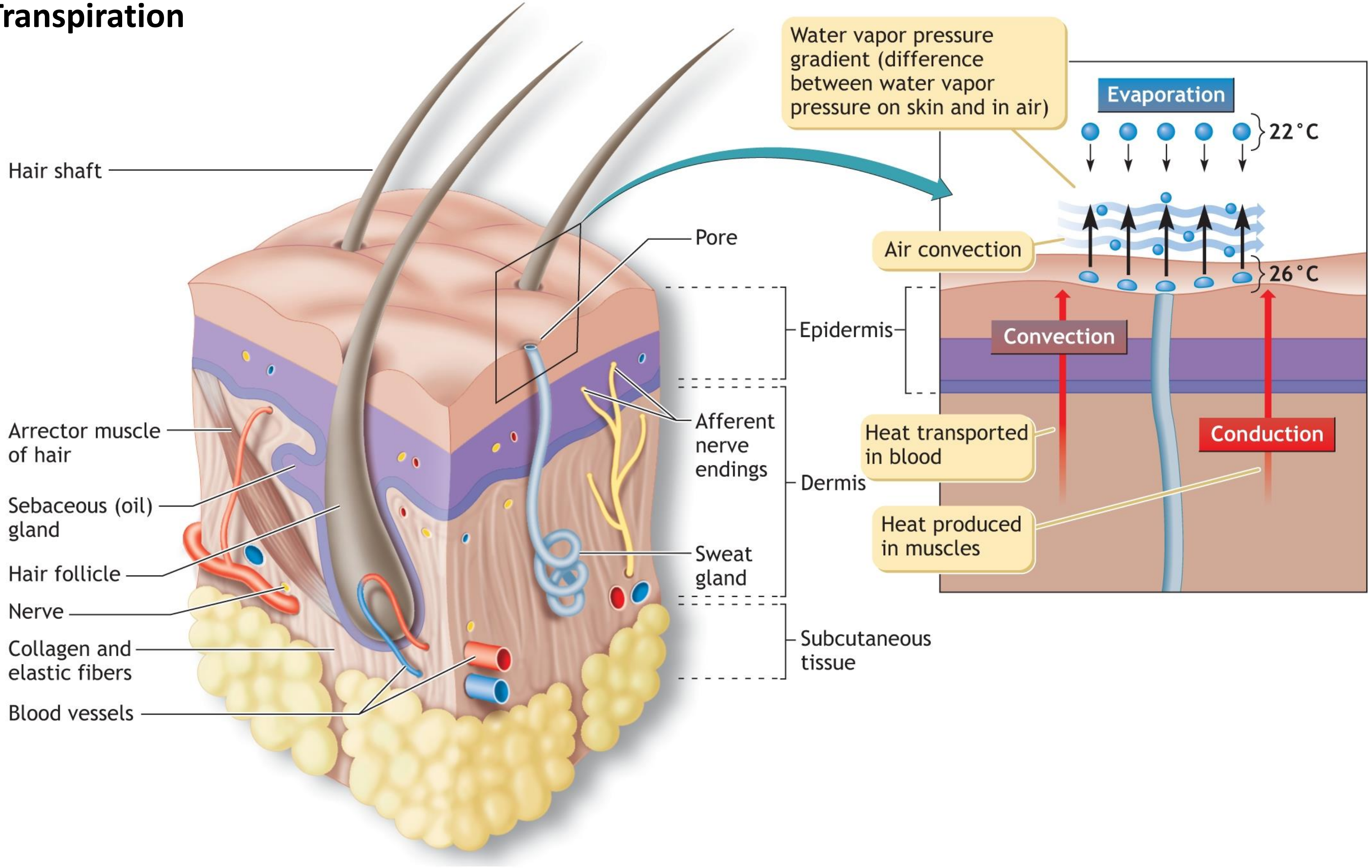
Figure 2 Net muscle glycogen utilisation (left panel) and blood lactate accumulation (right panel) during exercise at ~70% VO_2 peak in trained men at 20 and 40 °C. Values are means ± S.E. (n = 6–13). (*) Denotes different from 20 °C, $P < 0.05$. Data from Febbraio et al. (1994).

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Transpiration**



Thermorégulation

Exposition au chaud

Réponse physiologique

- **Transpiration**

Sudation, sueur < diaphorèse

Fluides secrétés par les glandes cutanées, innervées par neurones sympathiques cholinergiques

Glandes eccrines : principal type, sur tout le corps

forme de ressort, placées profondément dans le derme

a de longs tubes de sécrétion

secrète un liquide clair et ~ inodore

répondent a l'exercice et au stress émotionnel

→ Innervées par le système nerveux sympathique autonome

Fibres Cholinergiques + Adrénergiques

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Transpiration**

  Sudation, sueur < diaphorèse

  Fluides secrétés par les glandes cutanées, innervées par neurones sympathiques cholinergiques

Glandes apocrines : type minoritaire, seulement a certains endroits du corps

forme de ressort, placées entre le derme et le tissu adipeux

secrète dans le pore folliculaire

secrète un liquide huileux inodore dont protéines, stéroides, H2O + NaCl

devient odorant seulement en se décomposant

répondent au stress, a l' adrénaline

aisselles, oreilles, paupières, régions prégénitales, organes génitaux

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Transpiration**

Taux de sudation (L/h)

= { [***poids PRE*** *(kg) –* ***poids POST*** *(kg) -* ***volume d'urine*** *(L) +* ***volume de liquide ingéré*** *durant l'exercice (L)] /* ***durée*** *de l'exercice (h) }*

Thermorégulation

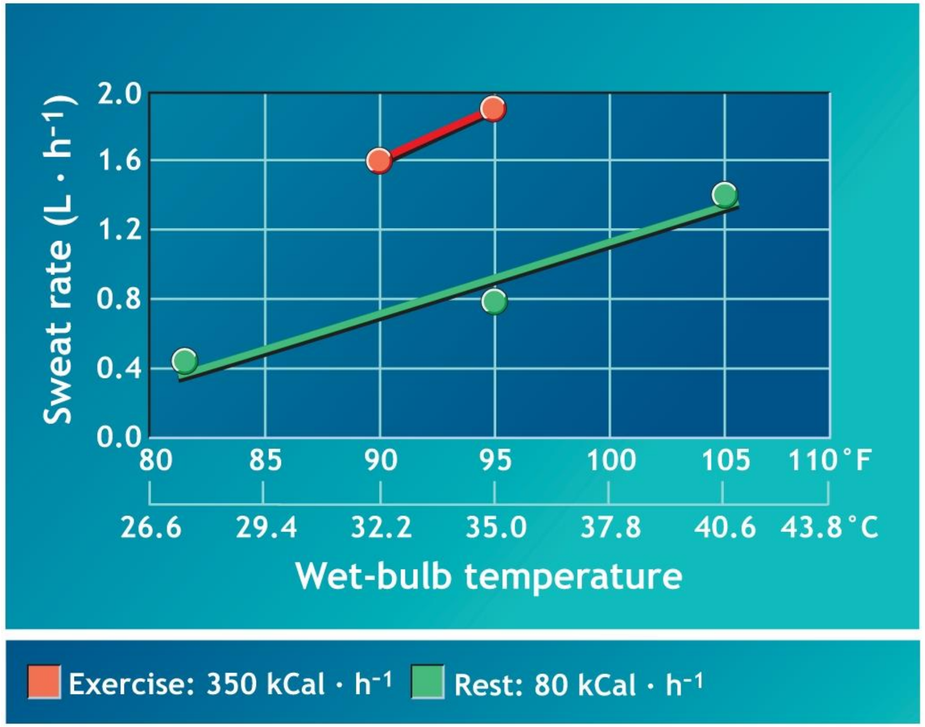
Exposition au chaud

Réponse physiologique

- **Transpiration**

Taux de production : 2-3 L/h et ~10-14 L/jour

~1 500 kcal/h



Variables

Sexe	*hommes > femmes*
Fitness	*entrainé > non-entrainé*
Acclimatation	*acclimatté > non- acclimaté*
Hydratation	*euhydraté > déshydraté*

Thermorégulation

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scandinavian Journal of Medicine and Science in Sports, 2010. 20(suppl. 3): p. 95-102

Exposition au chaud

Réponse physiologique

- **Transpiration**

Production de chaleur (en W)	w * v * a	poids / vitesse / coeff a = 2 pour marche, 4 pour course
Perte de chaleur par convection	$8.3(T_{SK} - T_A) \times \sqrt{V}$	W/m^2
Perte de chaleur par radiation	$5.2(T_{SK} - T_{MRT}) \times \sqrt{V}$	W/m^2
Pertes par évaporation	$124(P_{SK} - P_A) \times \sqrt{V}$	W/m^2
Surface corporelle	$0.007184 \times h^{0.725} \times w^{0.425}$	m^2

Thermorégulation

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scandinavian Journal of Medicine and Science in Sports, 2010. 20(suppl. 3): p. 95-102

Exposition au chaud

Réponse physiologique

- **Transpiration**

Production de chaleur (en W)	w * v * a	poids / vitesse / coeff a = 2 pour marche, 4 pour course

Simplification

Pertes par évaporation	$124(P_{SK} - P_A) \times \sqrt{V}$	W/m²
	$P = 10^{8.07131 - 1730.63/(233.426 + T_A)}$	
	http://www.respirometry.org/calculator/water-vapor-calculators	
Surface corporelle	$0.007184 \times h^{0.725} \times w^{0.425}$	m^2

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scandinavian Journal of Medicine and Science in Sports, 2010. 20(suppl. 3): p. 95-102

Exposition au chaud

Réponse physiologique

- **Transpiration**

poids	67	kg
taille	180	cm
BSA	1.85	m2
Ta	30	°C
Tsk	37	°C
RH%	80	%
Rendement	27	%
Vitesse	**3**	**m/s**

Chaleur	2894.4 * rend	= 781.5	W
E	348.8 * BSA	= 645.3	W
Stockage		136.2	W

Stockage de chaleur dans tissu humain

3.47 kJ / °C

Le coureur gagne 1°C toutes les

25.5 min

Thermorégulation

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scandinavian Journal of Medicine and Science in Sports, 2010. 20(suppl. 3): p. 95-102

Exposition au chaud

Réponse physiologique

- **Transpiration**

poids	67	kg
taille	180	cm
BSA	1.85	m2
Ta	**35**	°C
Tsk	37	°C
RH%	80	%
Rendement	27	%
Vitesse	3	m/s

Chaleur	2894.4 * rend	= 781.5	W
E	111.4 * BSA	= 206.1	W
Stockage		575.4	W

Stockage de chaleur dans tissu humain

3.47 kJ / °C

Le coureur gagne 1°C toutes les

6 min

Thermorégulation

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scandinavian Journal of Medicine and Science in Sports, 2010. 20(suppl. 3): p. 95-102

Exposition au chaud

Réponse physiologique

- **Transpiration**

poids	67	kg
taille	180	cm
BSA	1.85	m2
Ta	**35**	°C
Tsk	37	°C
RH%	80	%
Rendement	27	%
Vitesse	**5.4**	m/s

Chaleur	5209.9 * rend	= 1406.7	W
E	149.4 * BSA	= 276.5	W
Stockage		1130.2	W

Stockage de chaleur dans tissu humain

3.47 kJ / °C

Le coureur gagne 1°C toutes les

3.07 min

Thermorégulation

Maughan RJ. Distance running in hot environments: a thermal challenge to the elite runner. Scandinavian Journal of Medicine and Science in Sports, 2010. 20(suppl. 3): p. 95-102

Exposition au chaud

Réponse physiologique

- **Transpiration : limitations**

  - Pace (and therefore energy cost) is not constant, varying with tactics, terrain and wind
  - Environmental temperature and humidity vary over the duration of an event
  - Skin temperature and sweat distribution are not uniform over the whole skin surface
  - The whole body surface area is not available for heat exchange
  - Wind velocity is never constant, and may be very high over moving limbs
  - Vapor pressure depends on skin temperature and on osmolality at skin surface, and will fall as sweat evaporates, leaving a more concentrated salt solution behind

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Activation du système nerveux sympathique**

Débit cardiaque — $FC \times VS = Q_C$

Ajustements vasculaire — vasodilatation périphérique + constriction splanchnique

Régulation de la pression artérielle

- **± Activité musculaire**

réchauffe le sang

en fonction des thermorécepteurs cutanés et centraux — *~ individuel ~ fitness*

- si froid *effet vasoconstricteur sur derme*

- si chaud *effet vasodilatateur sur derme (jusqu'à 8 L/min)*

+ sudation…

Déplacement du volume de sang de la circulation centrale vers cutanée

↓SV entraine ↑FC = dérive cardiaque

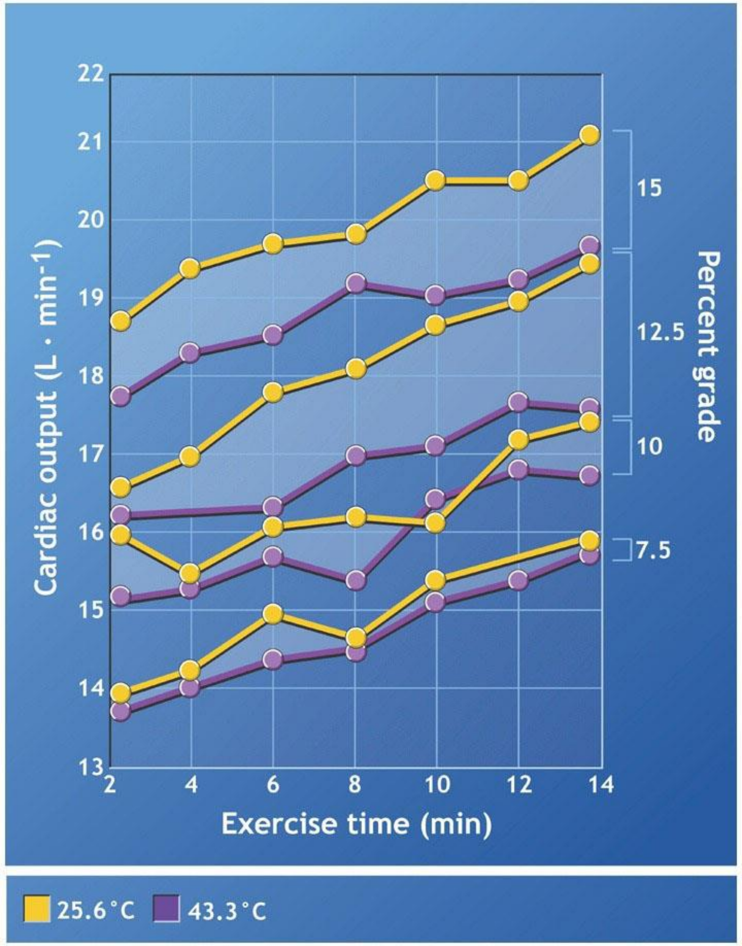
Thermorégulation

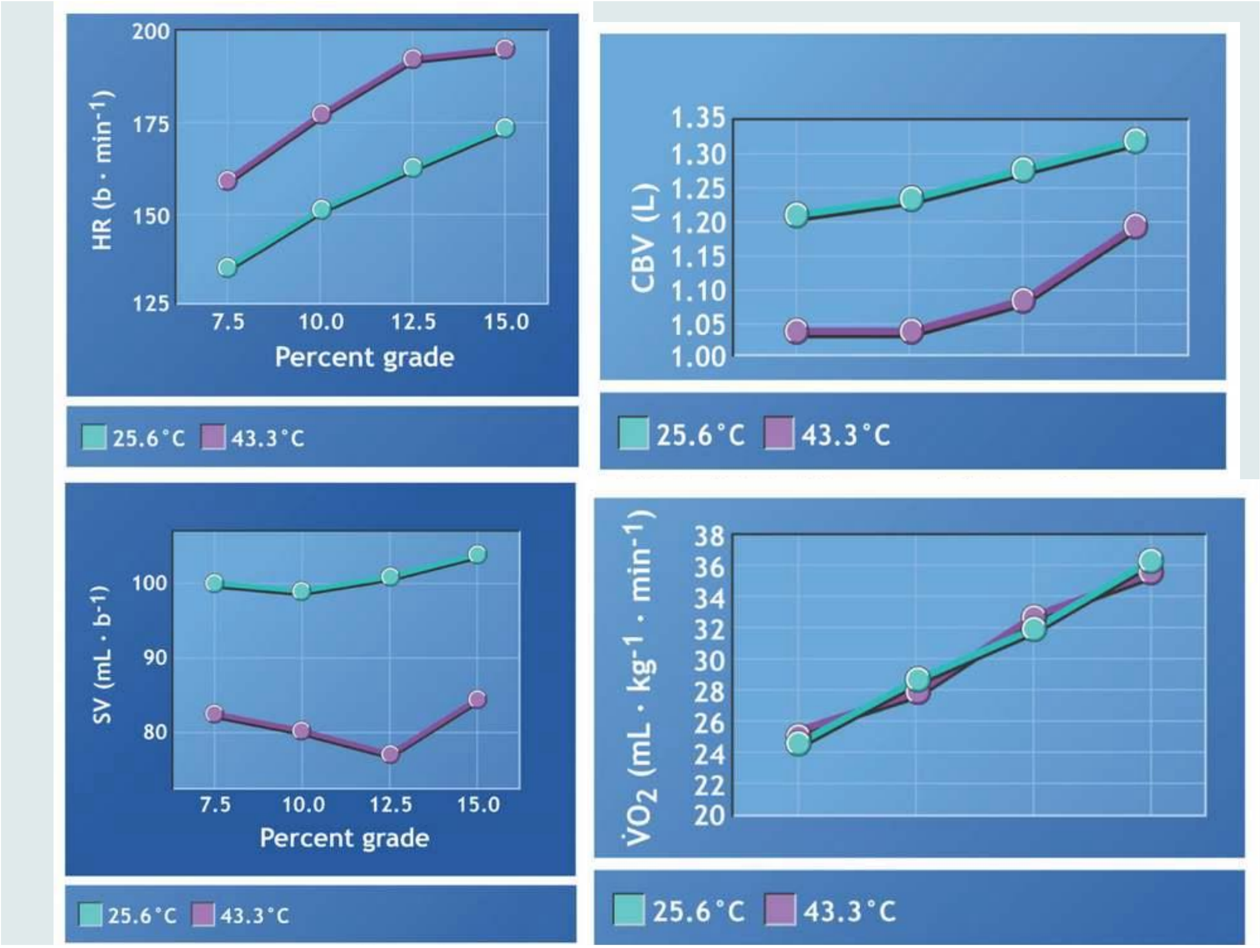
Exposition au **chaud**

Réponse physiologique

- **Système cardiovasculaire**

Rowell 1974





Thermorégulation

Exposition au chaud

<u>Réponse physiologique</u>

- **Dérive cardiaque** Rowell 1974

Augmentation	FC, skBF, skV	↑*compartiment vasculaire cutané*
Diminution	SV, P artérielle, P veineuse	↓*remplissage ventriculaire*

Augmentation de la T° centrale

Diminution de pression centrale	*Déplacement du volume sanguin*	Augmentation du flux sanguin cutané
Diminution de pression périphérique	*Compensation cardiaque*	Augmentation de la FC, diminution de SV

BUT = maintenir Q_C

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Intensité de l’exercice =** le facteur le plus important !

  Surtout chez les athlètes d'élite *Pugh 1972*

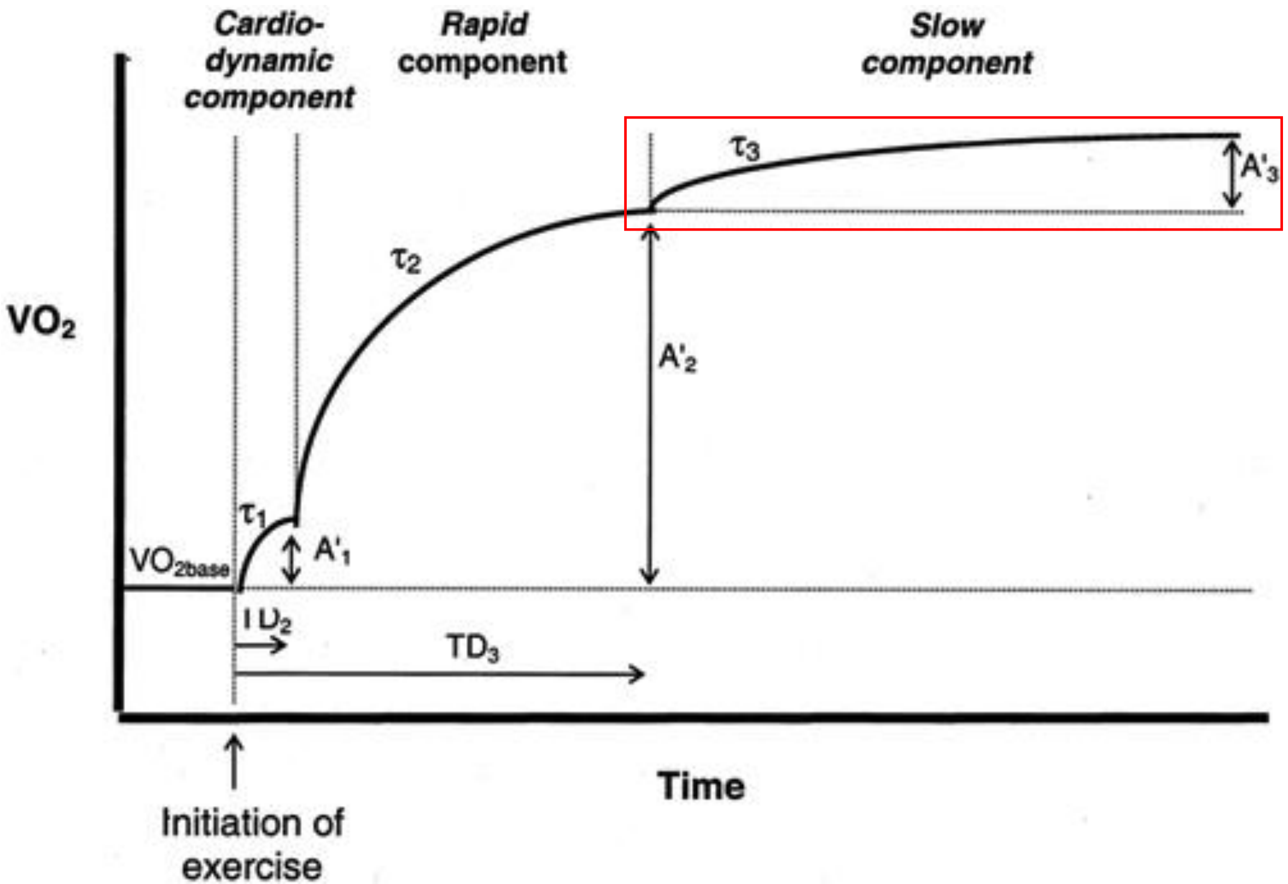
Thermorégulation

Exposition au **chaud**

Réponse physiologique

- **Intensité de l'exercice =** le facteur le plus important !

↑ composante lente de VO2



Thermorégulation

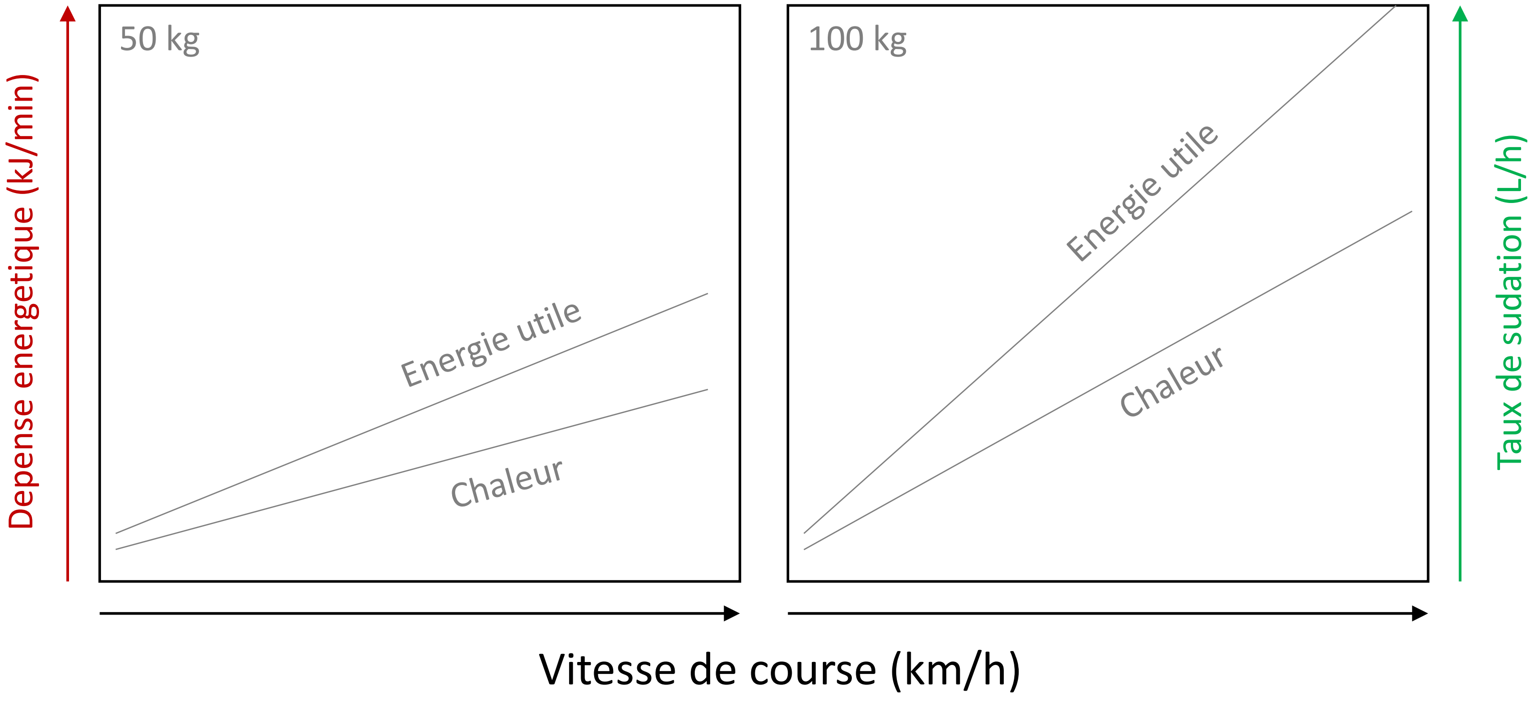
Exposition au chaud

Réponse physiologique

- **Intensité de l'exercice =** le facteur le plus important !

dépend de la stature ~20-30% de l'efficience

du taux de sudation



news24 archives
Breaking News. First.

6 die after traffic post fitness test

2012-12-29 17:40

Johannesburg - Six people have died from suspected dehydration after taking part in a KwaZulu-Natal traffic department recruitment fitness test, SABC news reported on Saturday.

Another person apparently committed suicide in frustration after the test, the news station reported.

Provincial Transport, Community Safety and Liaison MEC Willies Mchunu could not be reached for comment about the deaths.

However, in a statement on Saturday he said he would investigate the incident whereby "scores" of people who were trying to get a job at the road traffic inspectorate, collapsed during a fitness test.

"More than 34 000 applicants qualified for the 90 trainee posts which were advertised," said Mchunu in a statement.

He said that 15 600 applicants attended a fitness test at the Harry Gwala Stadium on Thursday, and a similar number attended on Friday.

"Scores of them could not cope with the hot weather conditions and collapsed."

Many were taken to hospital.

Mchunu said that he would meet with those in charge of the test on Saturday.

"We regret any injuries or loss of lives as a result of the fitness test," he said.

Comments

Thermorégulation

Exposition au chaud

Déshydratation

- **Effet du volume ingéré**

The purpose of this investigation was to determine the effect of different rates of dehydration, induced by ingesting different volumes of fluid during exercise, on hyperthermia, heart rate, and stroke volume. In addition, forearm blood flow, serum osmolality, and serum sodium concentration were measured to further characterize their relationship to hyperthermia during exercise-induced dehydration.

Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise

SCOTT J. MONTAIN AND EDWARD F. COYLE
Human Performance Laboratory, Department of Kinesiology and Health, The University of Texas at Austin, Austin, Texas 78712

Experimental design. On four different occasions, the subjects exercised continuously for 2 h on a cycle ergometer (Jaeger) in a warm environment (32.7 ± 0.2°C dry bulb, 50 ± 2% relative humidity, wind speed 2.5 m/s) at a power output (206 ± 14 W) that initially elicited 62% of $\dot{V}O_{2\,max}$. During exercise, the subjects randomly received no fluid (NF) or ingested a small (SF), moderate (MF), or large (LF) volume of fluid, which replaced 20 ± 1, 48 ± 1, and 81 ± 2%, respectively, of the fluid lost in sweat during exercise. The fluid replacement solution was a commercially available carbohydrate-electrolyte beverage (Gatorade, Quaker Oats). All trials were separated by ≥72 h.

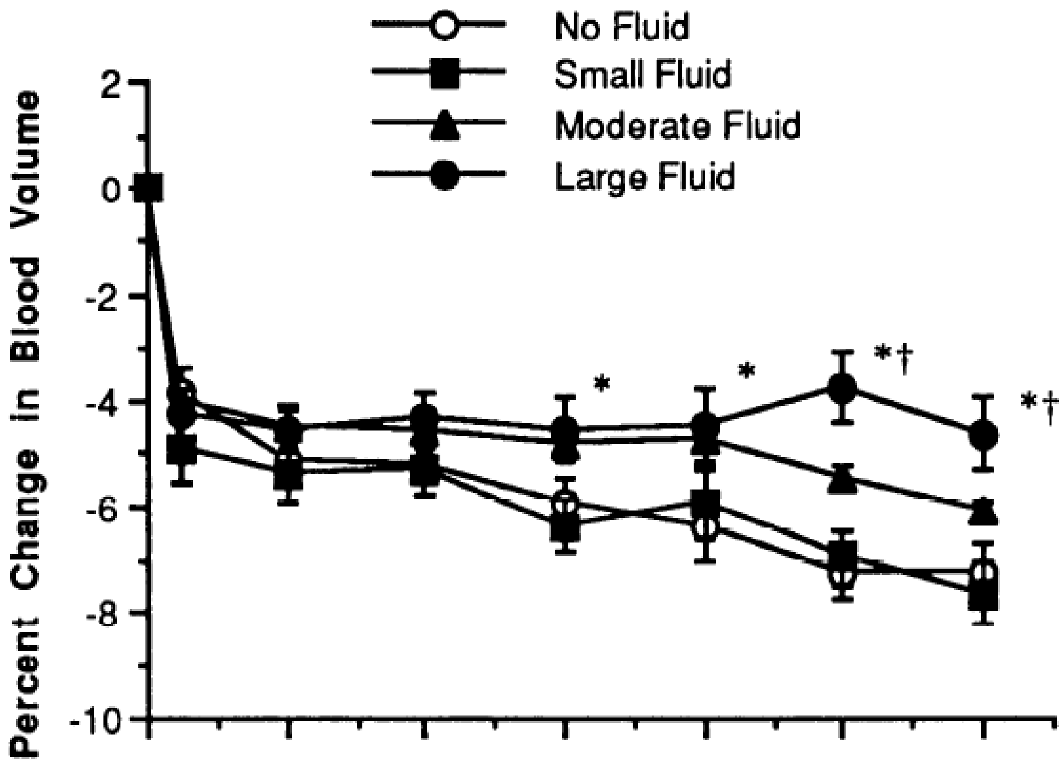
wind speed 2.5 m/s). During exercise, they randomly received no fluid (NF) or ingested a small (SF), moderate (MF), or large (LF) volume of fluid that replaced 20 ± 1, 48 ± 1, and 81 ± 2%, respectively, of the fluid lost in sweat during exercise. The pro-

Montain SJ, Coyle EF. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. Journal of Applied Physiology, 1992. 73(4): p. 1340-1350

Exposition au chaud

Déshydratation

- **Effet du volume ingéré**



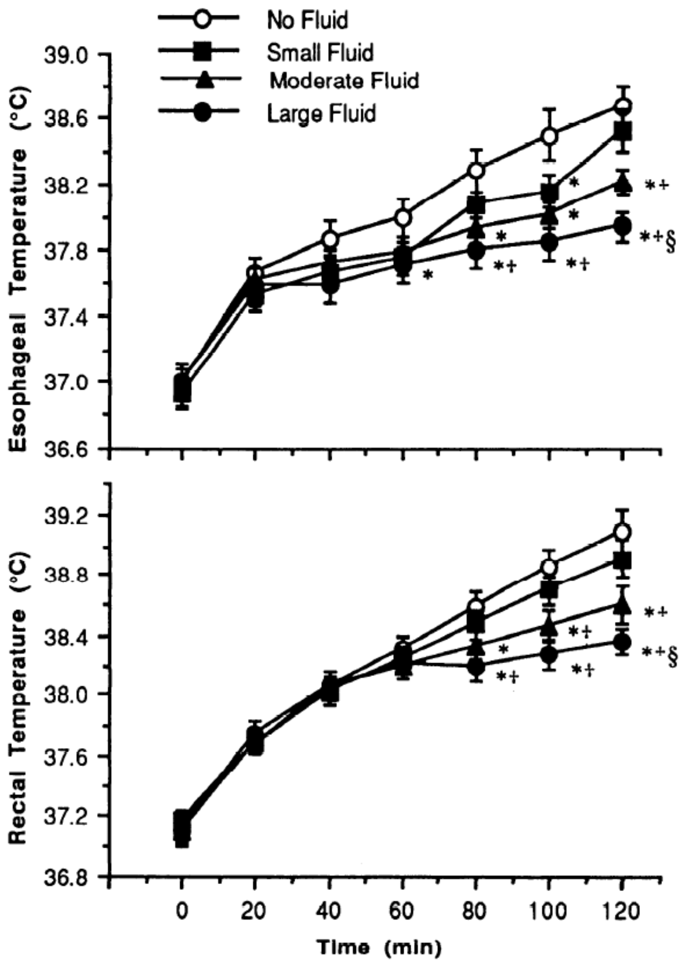


FIG. 1. Esophageal (n = 7) and rectal (n = 8) temperatures during 120 min of exercise when no fluid or small, moderate, or large volume of fluid was ingested. Values are means ± SE. *Significantly lower than no fluid, $P < 0.05$. †Significantly lower than small volume of fluid, $P < 0.05$. §Significantly lower than moderate volume of fluid, $P < 0.05$.

Montain SJ, Coyle EF. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. Journal of Applied Physiology, 1992. 73(4): p. 1340-1350

Exposition au chaud

Déshydratation

- **Effet du volume ingéré**

In summary, we found that the magnitude of hyperthermia and cardiovascular drift during 2 h of moderate-intensity exercise in a thermally stressful environment was directly related to the magnitude of dehydration accrued during exercise. Thus the optimal rate of fluid replacement to attenuate hyperthermia and cardiovascular drift during prolonged exercise is the rate that most closely matches sweat loss, at least up to 81% fluid replacement. Fluid ingestion attenuated hyperthermia by promoting higher skin blood flow during the 2nd h of exercise, with the greatest rates of skin blood flow occurring when the largest volumes of fluid were ingested during exercise. Finally, the high correlations between increase in T_{es} and increase in both serum osmolality and serum sodium concentration during prolonged exercise suggest that the goal of fluid ingestion may be to prevent

Thermorégulation

Almond CSD, Shin AY, Fortescue EB, Mannix RC, Wypij D, Binstadt BA, Duncan CN, Olson DP, Salerno AE, Newburger JW, Greenes DS. Hyponatremia among runners in the Boston Marathon. The New England Journal of Medicine, 2005. 352: p. 1550-1556

Exposition au chaud

Réhydratation

- **Faut-il remplacer les pertes ?**

= stratégies agressives > 1 L/h

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Hyponatremia among Runners in the Boston Marathon

Christopher S.D. Almond, M.D., M.P.H., Andrew Y. Shin, M.D.,
Elizabeth B. Fortescue, M.D., Rebekah C. Mannix, M.D., David Wypij, Ph.D.,
Bryce A. Binstadt, M.D., Ph.D., Christine N. Duncan, M.D.,
David P. Olson, M.D., Ph.D., Ann E. Salerno, M.D.,
Jane W. Newburger, M.D., M.P.H., and David S. Greenes, M.D.

CONCLUSIONS

Hyponatremia occurs in a substantial fraction of nonelite marathon runners and can be severe. Considerable weight gain while running, a long racing time, and body-mass-index extremes were associated with hyponatremia, whereas female sex, composition of fluids ingested, and use of nonsteroidal antiinflammatory drugs were not.

Thermorégulation

Exposition au chaud

Réhydratation

- **Faut-il remplacer les pertes ?**

= stratégies agressives > 1 L/h

ACSM « position statement » = ~1,2 L/h

1975 “Athletes should be encouraged to frequently ingest fluids during competition”

1987 “Fluid ingestion before and during the race will reduce the risk of heat injury, particularly in the longer runs such as the marathon”

1996 “dehydration during exercise presents the potential for the development of heat-related disorders... Including the potentially life-threatening heatstroke. It is therefore reasonable to surmise that fluid replacement that offsets dehydration (...) may be instrumental in reducing the risk of thermal injury”

Thermorégulation

Exposition au chaud

Réhydratation

- **Faut-il remplacer les pertes ?**

= stratégies agressives > 1 L/h

Nevada Desert Study *Adolph 1947 cited in Noakes 1993*

Participants buvaient moins que les pertes de transpiration
Déshydratation associée avec développent de fatigue
Epuisement ~ 7-10%$_{BW}$ déshydratation
Pas de risques immédiats sur la santé

During Ironman triathlon... *Laursen, Suriano, Quod et al. 2006*

3% de perte de poids de corps
participants toujours considérés comme "euhydratés"

[Na]	~ normal
T° centrale	~ normal

Waterlogged *Noakes 2012*

"drink as much as you can" est une erreur
fait courir plus de risques qu'une déshydratation modérée
Exercise-induced hyponatremia

Thermorégulation

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Exposition au chaud

Stratégies

- **Pre-cooling**

Getty

Almond CSD, Shin AY, Fortescue EB, Mannix RC, Wypij D, Binstadt BA, Duncan CN, Olson DP, Salerno AE, Newburger JW, Greenes DS. Hyponatremia among runners in the Boston Marathon. The New England Journal of Medicine, 2005. 352: p. 1550-1556

Exposition au chaud

Stratégies

- **Per-cooling**

Bongers CCWG, Thijssen DHJ, Veltmeijer MTW, Hopman MTE, Eijsvogels TMH. Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review. British Journal of Sports Medicine, 2014. 49(6): p. 377-384

Exposition au chaud

Stratégies

- **Pre-cooling + Per-cooling**

Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review

Coen C W G Bongers,[1] Dick H J Thijssen,[1,2] Matthijs T W Veltmeijer,[1] Maria T E Hopman,[1] Thijs M H Eijsvogels[1,3]

This meta-analysis demonstrated a significant impact of the type of cooling strategy when performing precooling to enhance exercise performance. Our analysis revealed that a combination of techniques (ie, mixed method precooling) had a significantly larger effect than individual cooling techniques (cold water/ice slurry ingestion, cooling vests, cooling packs or cold water immersion alone). This observation is reinforced by a study which examined three precooling strategies: (1) cooling pack, (2) cooling pack + cold water immersion and (3) cooling pack + cold water immersion + ice vest.[27] While no effect was found for the cooling pack, both mixed method cooling trials effectively improved exercise performance.[27] The higher cooling capacity in the mixed method cooling compared with individual cooling strategies most likely contributes to this finding. Mixed techniques with an 'aggressive' approach and affecting a large body surface especially seem to contribute to a larger effect on exercise performance. The law of enthalpy of

Table 2 Overview of subtotal effect sizes±95% CI of different cooling techniques for the precooling and percooling interventions

	Number of studies	Precooling	Number of studies	Percooling
Cooling vest	6	0.19 (0.10 to 0.28)	1	4.64 (0.96 to 8.32)
Cold water immersion	5	0.49 (0.09 to 0.90)	–	NA
Cold water ingestion	6	0.40 (0.17 to 0.62)	1	1.75 (0.38 to 3.12)
Cooling packs	2	0.40 (0.10 to 0.71)	7	0.34 (0.09 to 0.58)
Mixed method cooling	8	0.72 (0.49 to 0.96)	–	NA
Average effect size	27	0.44 (0.31 to 0.56)	9	0.40 (0.15 to 0.66)

NA, not available.

Thermorégulation

Best R, Payton S, Spears I, Riera F, Berger N. Topical and Ingested Cooling Methodologies for Endurance Exercise Performance in the Heat. Sports, 2018. 6(1): p. 11

Exposition au chaud

Stratégies

- **Pre-cooling + Per-cooling**

Author	Participants	Timing	Intervention	Modality	Outcomes
Ross et al., 2011	11	Precooling	Ice	Cycling	TT, PO, T_{rec}, TC
Ross et al., 2012	12	Precooling	Ice + T, Ice + G + T	Cycling	TT, PO, RPE, TC
Muñoz et al., 2012	10	Percooling	OR, EXC, EXC + OR	Running	TT, T_{rec}, TC, RPE
Stanley et al., 2010	10	Percooling	Ice, COOL	Cycling	TT, PO, T_{rec}
Stevens et al., 2013	9	Percooling	Ice	Triathlon/Running	TT, T_{rec}, RPE, TC
Stevens et al., 2015	11	Precooling/Percooling	Ice, M	Running	TT, T_{rec}, RPE, TS
Stevens et al., 2017	9	Percooling	M	Running	TT, T_{rec}, RPE, TS
Riera et al., 2014	12	Combined	N, N + M, COOL, COOL + M, Ice, Ice + M	Cycling	TT, TC, TS, RPE
Tran Trong et al., 2015	10	Combined	N + M, COOL + M, Ice + M	Cycling/Running	TT, TC, TS, RPE
Schulze et al., 2015	7	Combined	Ice, PC + Ice	Cycling	TT, PO, T_{rec}, TC, TS

Intervention Methodologies: COOL: cool liquid ingestion; EXC: external cooling via pouring cold water; G: glycerine; Ice: ice slurry ingestion; N: ambient temperature water; M: menthol; OR: oral rehydration; T: iced towels applied to participants. Outcome Variables: TT: time trial performance; PO: power output; RPE: rating of perceived exertion; T_{rec}: rectal temperature; TC: thermal comfort; TS: thermal sensation.

sports MDPI

Review

Topical and Ingested Cooling Methodologies for Endurance Exercise Performance in the Heat

Russ Best [1,2,*], Stephen Payton [3], Iain Spears [4], Florence Riera [5,6] and Nicolas Berger [1]

This meta-analysis aimed to assess the effects of practical precooling and percooling strategies applied to trained endurance athletes exercising in hot environmental conditions. Our main finding was that combining precooling and percooling timings has a cumulative beneficial effect upon endurance time trial performance, compared to when precooling and percooling are implemented in isolation (Figure 2a). Our secondary finding was that ingested cooling methods outperform topical, or a combination of methods, suggesting method of delivery affects the performance enhancing capabilities of cooling interventions (Figure 2b). Therefore, when competing in the heat, we recommend ingesting cold liquids or ice slurries before and during competition.

Thermorégulation

Exposition au chaud

Réponse physiologique

- **Acclimatation**

Méthode : *Armstrong, Maresh 1991, Shapiro et al. 1998*

exercice journalier a 50% VO_{2MAX}

augmenter la duree graduellement de 30 à 100 min

durant 10 à 14 jours, potentiellement jusqu'à 30 jours pour effets a plus long terme

puis les effets durent de 7 à 28 jours

Leviers supplémentaires : Sauna, vêtements + exercice

Thermorégulation

Exposition au chaud

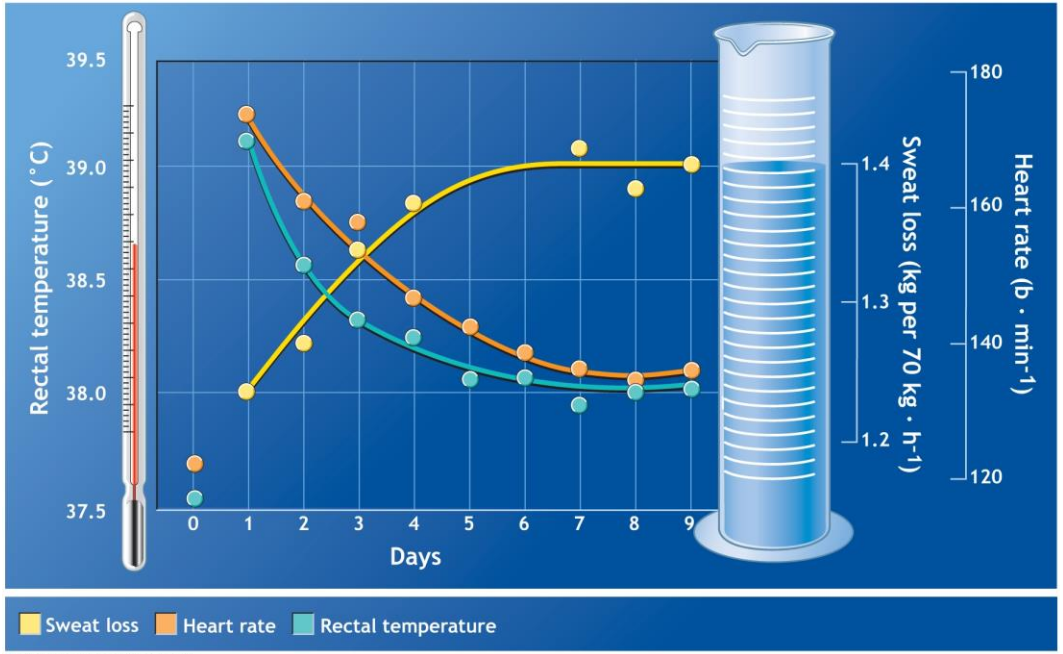
Réponse physiologique

- **Acclimatation**

Transpiration accrue = meilleure sudation

Moindre menace pour l’homéostasie et la sante

Moindre dérive cardiaque



Thermorégulation

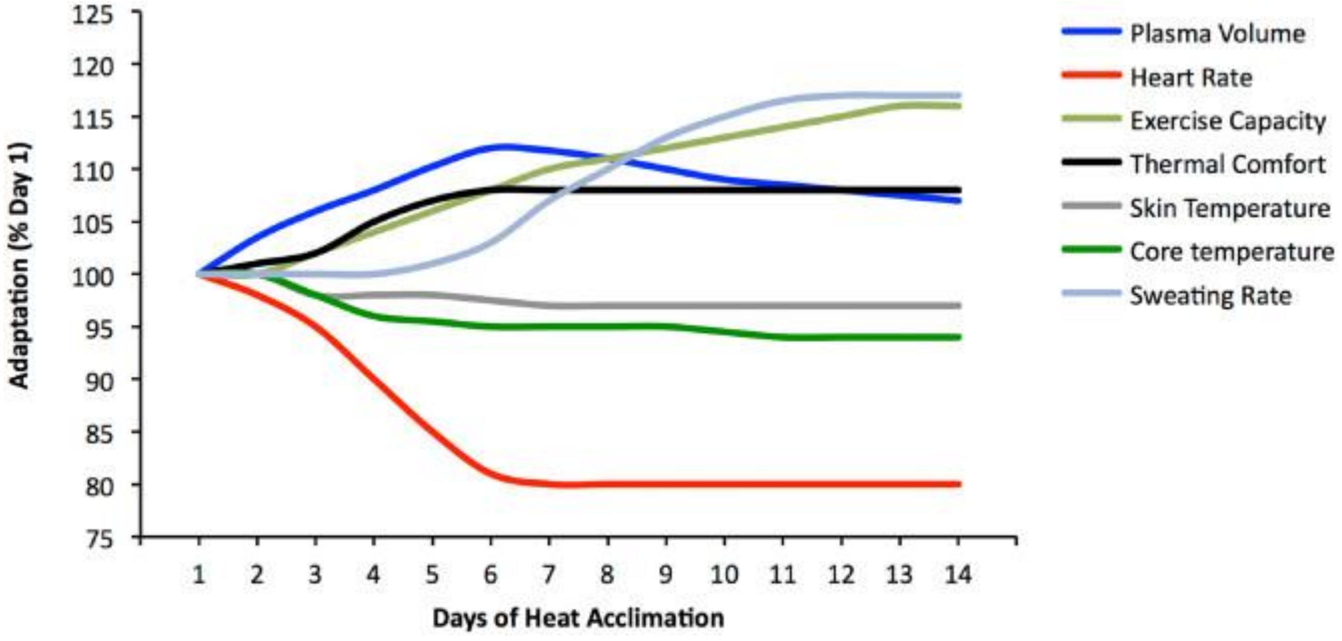
Exposition au chaud

Réponse physiologique

- **Acclimatation**

A intensité d'exercice égale (relative), l'acclimatation

- diminue FC, T°, [La]
- diminue le cout métabolique
- diminue l'utilisation de CHO
- accroit le taux de sudation
- Rétention d'eau
  - Augmente la masse (pas top)
  - Mais aussi augmente volume plasmatique (3-4 j)



Thermorégulation

Exposition au chaud

Réponse physiologique

- **Acclimatation**

Athlètes s'entrainant en environnement froid performent moins bien dans la chaleur

Athlètes s'entrainant en environnement chaud performent ~ aussi bien dans le froid

Heat acclimatization does/does not improve exercise performance in a cool condition: relevance for sprint performance

F. Brocherie[1,2], G.P. Millet[1,2] and O. Girard[1,2]
[1] *ISSUL, Institute of Sports Sciences, University of Lausanne, Switzerland*
[2] *Department of Physiology, Faculty of Biology and Medicine, University of Lausanne, Switzerland*

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conditions. That said, in the absence of available study with sprint tests conducted in cool conditions after 'heat training', the superior efficiency of heat acclimatization/acclimation to improve sprint performance in hot *vs.* cool environments is simply unproven.