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Hot Weather Management in Sailing

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Outline

- Principles of ***thermal balance*** across the human body
- ***Assessment of thermal strain*** on human physiology
- Strategies to ***mitigate thermal strain in sailing***
- ***Design and materials for sailing garments***

- Polito Sailing Team

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PRINCIPLES OF HUMAN THERMAL BALANCE

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Energy balance

Thermophysiological comfort is based on the **principle of energy conservation**. All energy produced within the body by metabolism has to be dissipated in exactly the same amount from the body, to keep body temperature constant:

$$M-W=Q_{res}+Q_{sk}+\Delta E$$

where:

- M is the energy produced by the body by metabolism
- W is the external work (running, swimming, sailing)
- Q_{res} is the total respiratory heat loss because of breathing
- Q_{sk} is the total heat lost from the skin surface
- ΔE is the energy stored

If more energy is produced than dissipated ($\Delta E>0$), the body suffers from hyperthermia. On the other hand, too high a heat loss leads to hypothermia($\Delta E<0$). Steady state: $\Delta E=0$

$$M - W = Q_{res} + Q_{sk} + \Delta E$$

total heat generated within the human body

total heat lost from the human body

total energy stored in the human body

- $H = M - W$

It results from the energy produced by biochemical mechanisms within the cells minus the energy that is transformed into mechanical work

- $Q_{res} = C_{res} + E_{res}$

The total heat loss by respiration (Q_{res}) includes sensible heat flow (C_{res}) and latent heat flow from the evaporation of moisture during respiration (E_{res}).

- $Q_{sk} = C_{sk} + R_{sk} + E_{sk}$

The total heat loss from the skin surface (Q_{sk}) includes the heat loss by conduction (C_{sk}), the heat loss by radiation (R_{sk}) and the evaporative heat due to sweating and perspiratio insensibilis (E_{sk})

Mechanisms of heat exchange through garments

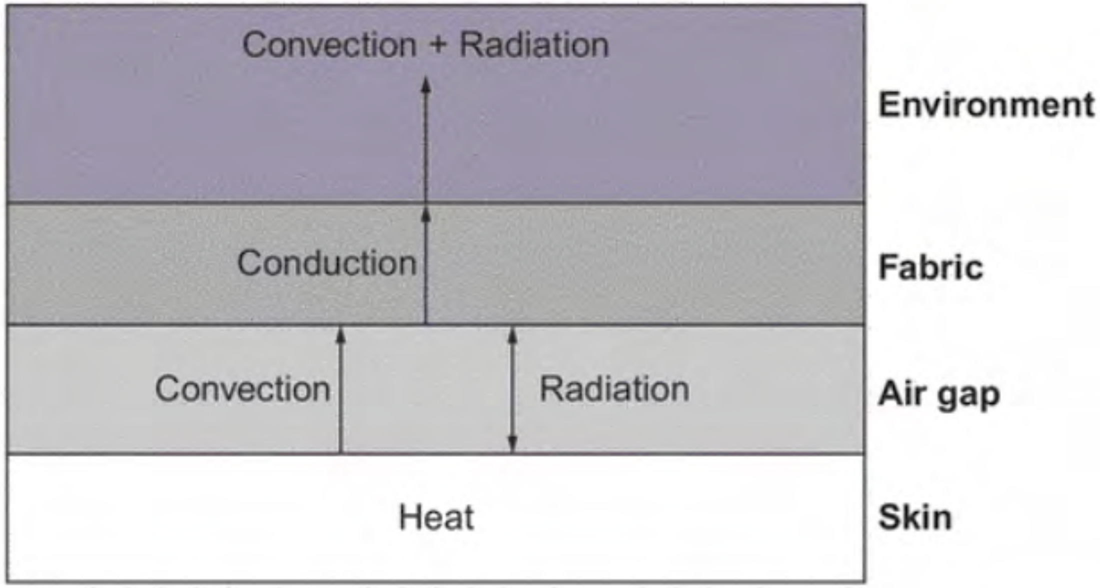

Fig. 10.1 Path[illegible] of heat transfer from the skin to the environment through textiles.

Source: Ke Y. Et al., Warmth without the weight, Engineering of High-Performance Textiles, Woodhead publishing (2018)

In non-sweating conditions, thermal radiation (7-14 μm) accounts for 40-60% of heat loss from the body

Why so much heating?

H=M-W

M=metabolic rate

W=mechanical output

Gross Efficiency (GE)≈20%

W=100 Watt

M=500 Watt H=400Watt

Unit for energy cost of physical activities.
1 Met= energy expenditure at rest (BMR)=60 Watt/m^2

http://www.pianetaciclismo.com

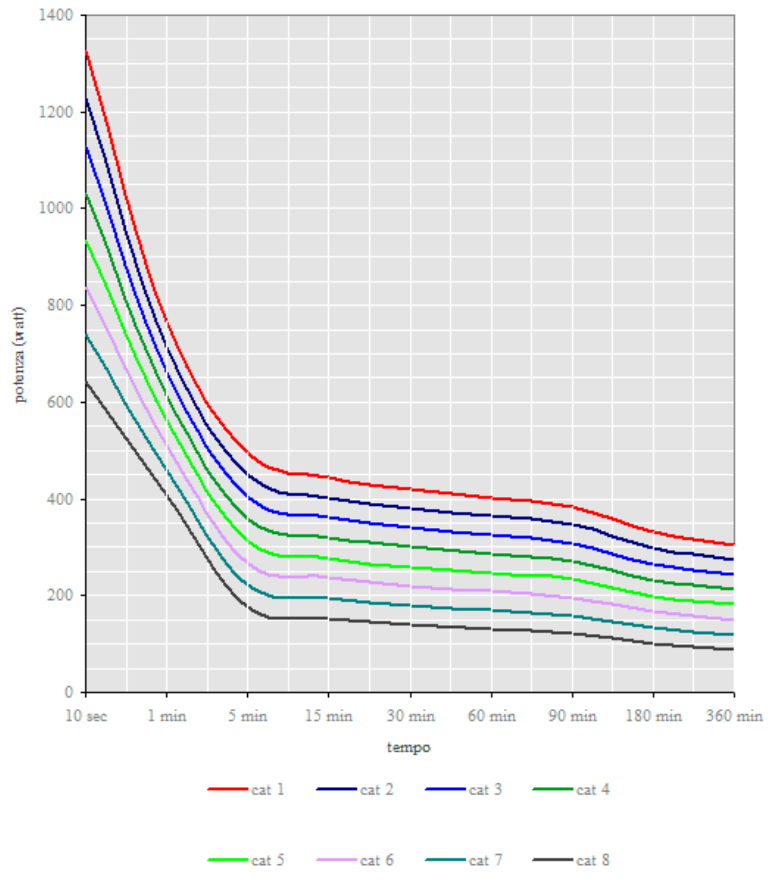

Fig.5: Curve medie di prestazione in funzione del tempo per le 8 categorie qualitative.

Energy expenditure of different sports

- 1 Met=3.5 mL O_2/min/kg

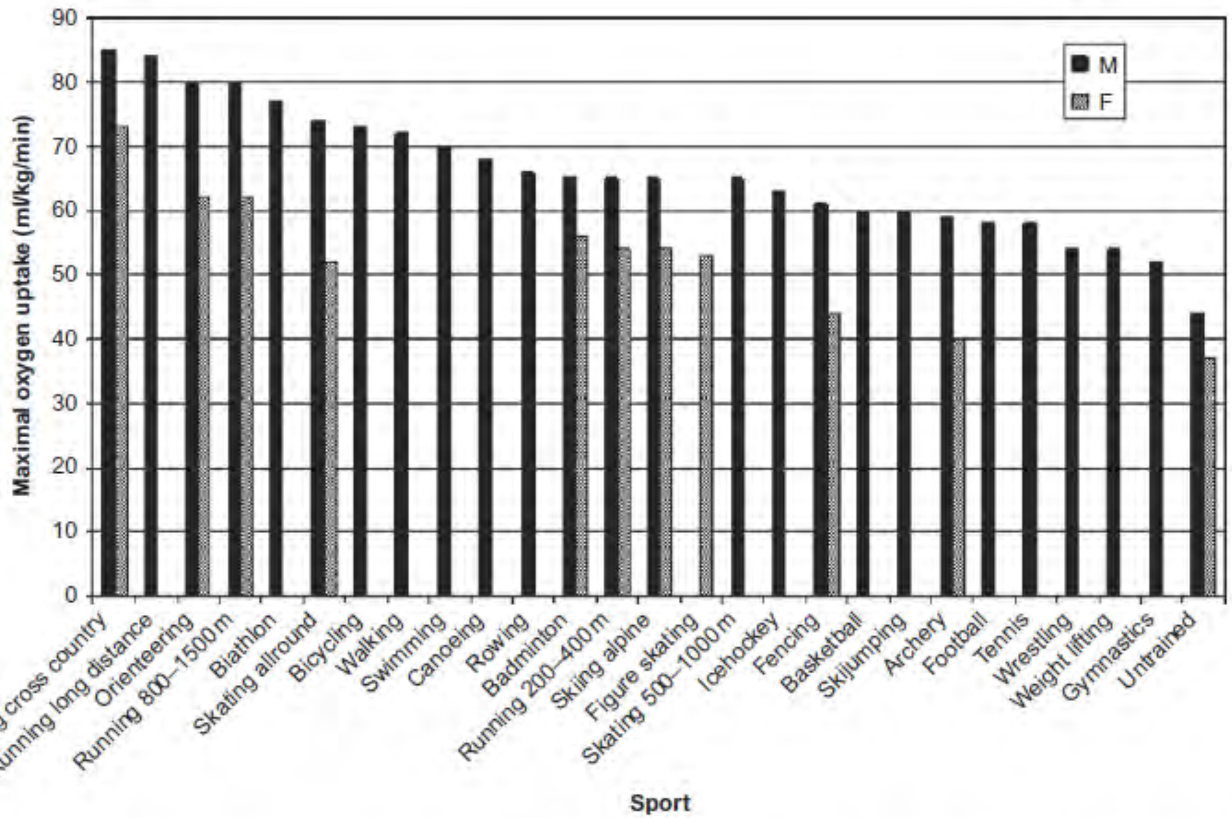

Figure 7.2 Average maximal oxygen uptake in milliliters per kg body mass per minute for male (black bars) and female (grey bars) Swedish national teams in different sports. Revised from Astrand et al. (2003).

Castagna et al. (2007; 2008) reported oxygen uptake values of **65 ml*kg-1*min-1, or above 80% of VO2max, with heart rates above 90% of HRmax and serum lactate exceeding 10 mmol*l-1** in elite Olympic board sailors

- Olympic boardsailing requires a **high contribution of aerobic and anaerobic metabolism**, and may in certain conditions and phases of the race be considered as physically demanding as e.g. bicycle racing or cross country running.
- Sailors have a well-developed capacity to develop high anaerobic power (**mean and peak power of ~8 and ~11 W*kg-1 respectively**) comparable to that of swimmers and middle distance runners.

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Journal of Sports Sciences

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http://www.informaworld.com/smpp/title~content=t713721847

Sailing physiology

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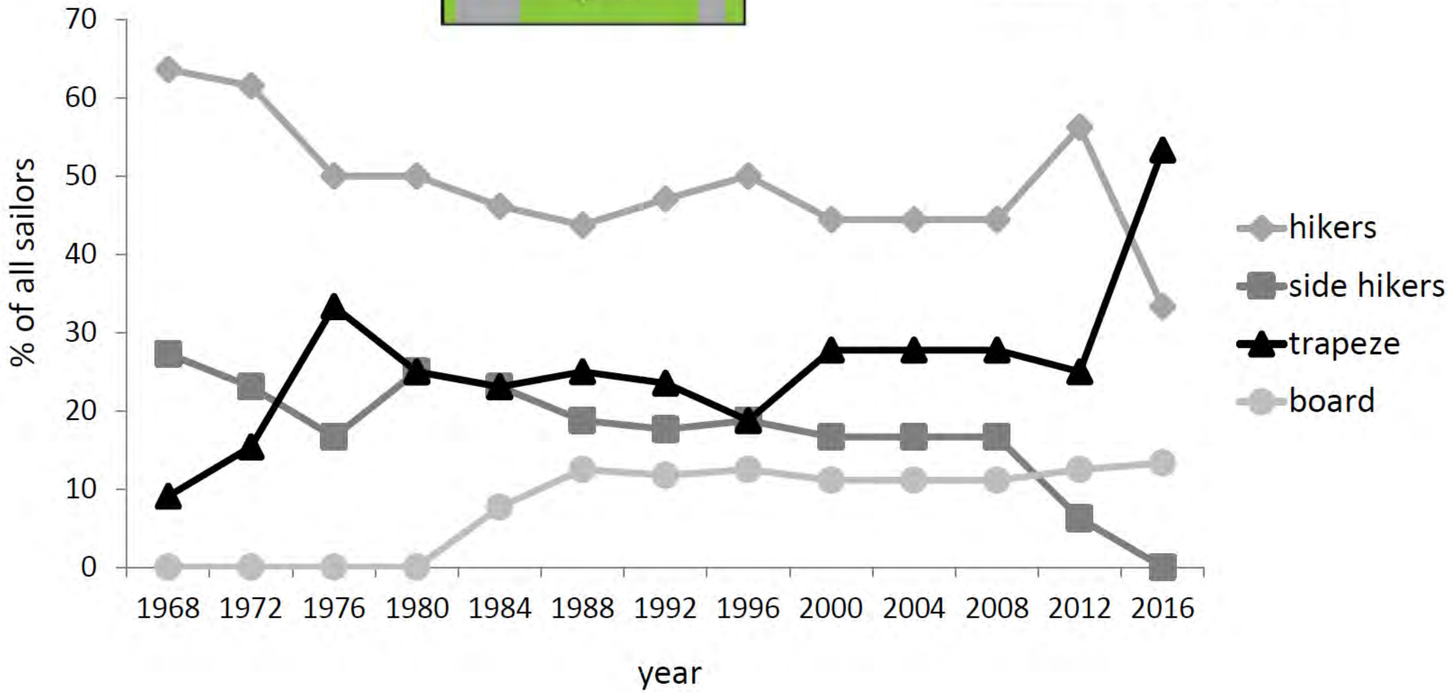
To link to this article: DOI: 10.1080/02640410601165171
URL: http://dx.doi.org/10.1080/02640410601165171

PLEASE SCROLL DOWN FOR ARTICLE



- The data are based on more than 400 single physical tests on ~120 sailing athletes examined during a 25-year time period.

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ASSESSMENT OF THERMAL STRAIN ON HUMAN PHYSIOLOGY IN SAILING

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Thermoregulatory demands of Elite Professional America's Cup Yacht Racing

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Scand J Med Sci Sports 2010: 20: 475–484
doi: 10.1111/j.1600-0838.2009.00952.x

The physiological and technical demands are specific to the **role of the athlete** and largely dependent on the **wind strenght** and **race tactics**.

In some roles, sailors are reported working at **90% of VO_{2peak}**
Results: elevated body temperature, substantial sweat losses during racing.

RISKS: DEHYDRATION, HEAT ILLNESS

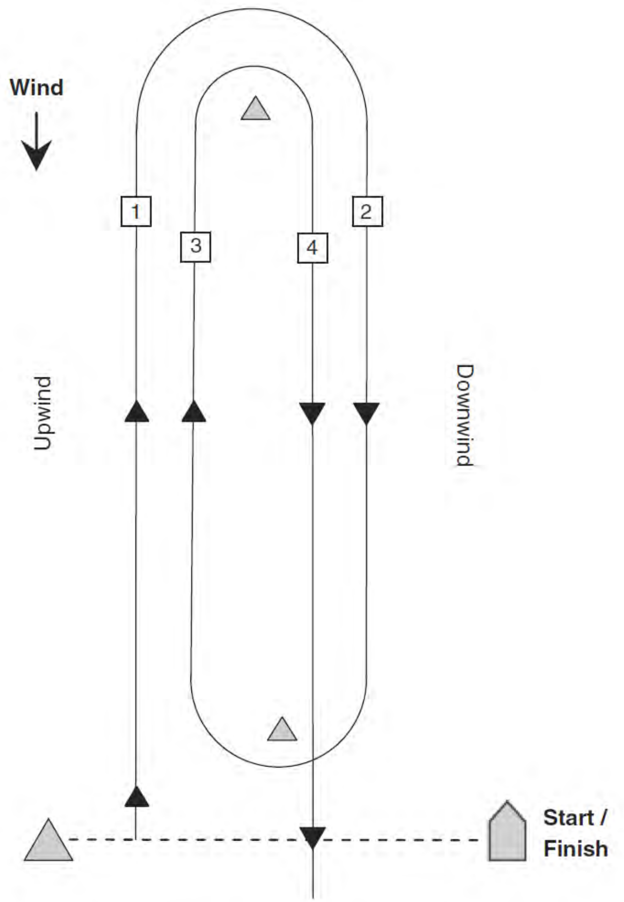
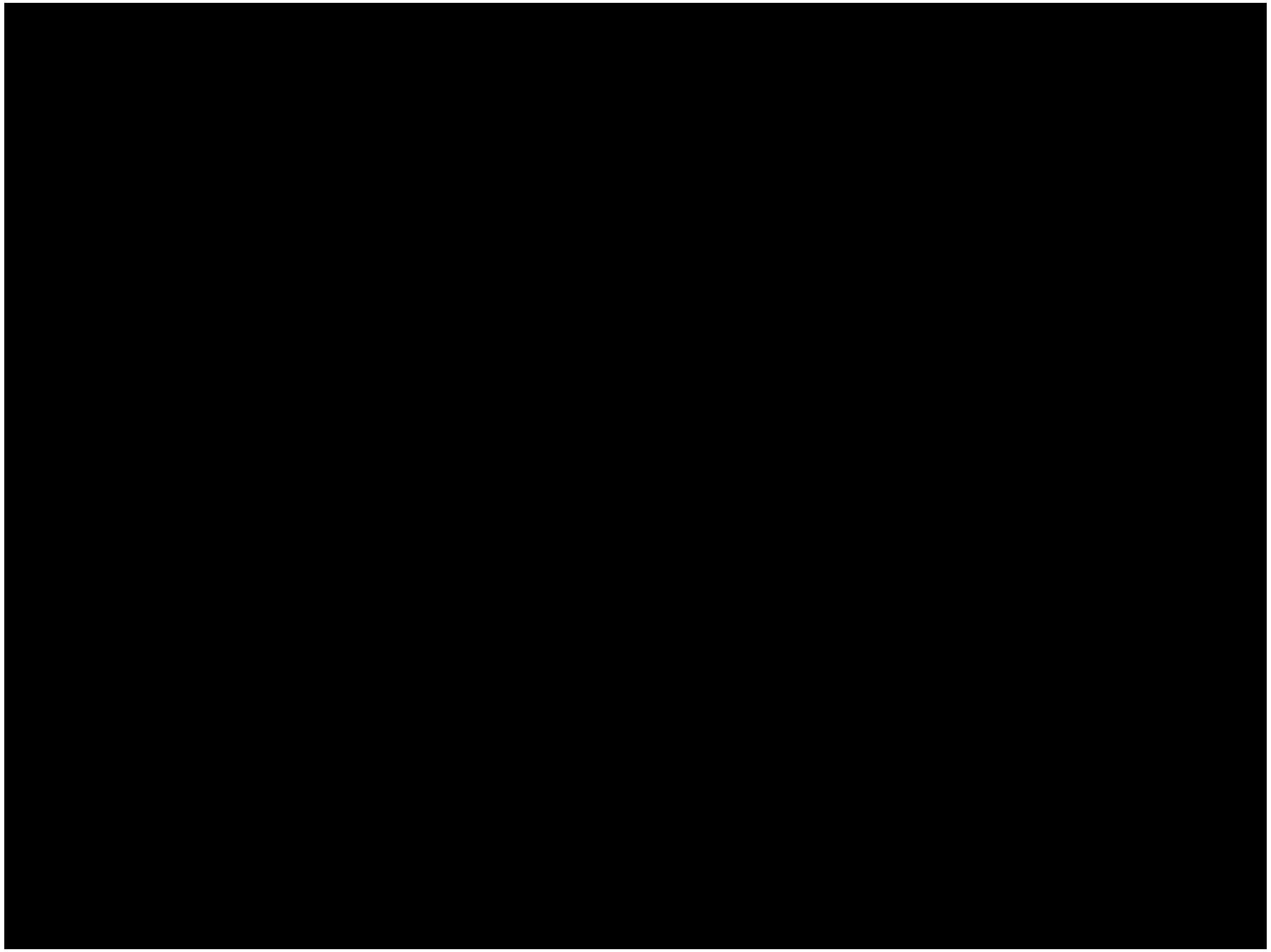


Fig. 1. An America's Cup match-race course, with each leg being approximately 5.6 km (3.0 nautical miles) in length.

- Large differences in the Apparent Wind Speed (AWS) between upwind and downwind sailing.
- Upwind sailing results in sailing against prevailing waves, with increased expusure to **sea spray and greater AWS (cool)**.
- **Athletes are unable to change garments in response to different conditions.**
- **RESULT**: high rate of heat storage and restricted evaporative loss **during downwind sailing (hot)**

Evaporative cooling: a mantra for sportswear manufacturers!



Core and skin temperature in-field measurements

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32 elite, male America's Cup athletes participated in the study

CorTemp® Core Body Temperature Monitors

equivital™

e-Celsius Performance

°myTemp

4 types of ingestible telemetric core temperature sensors are available on the market

Wireless skin temperature sensors (chest, anterior calf, thigh, forearm)

Absorbent sweat collection patches (laboratory analysis of sodium, potassium and chloride concentrations).

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- **Environmental conditions:**

  T =32±1°C

  RH=52±5%

  True wind speed=5.0±0.2 m/s

  AWS upwind= 9.2 m/s

  AWS downwind=2.4 m/s

- **Field test:**

  65-min short course two lap race (2.8 km per leg)

  35-min short course one lap race

  23-min active recovery

Table 1. Physical characteristics of America's Cup yacht racing athletes, including laboratory-tested maximum heart rate (HR) and unpublished HR data recorded during strenuous racing

	All ($n = 32$)	(Range)	*Bowmen* ($n = 6$)	*Grinders* ($n = 8$)	*Utilities* ($n = 6$)	*Trimmers* ($n = 6$)	*Afterguard* ($n = 6$)
Age (years)	36 ± 7	(25–47)	36 ± 5	36 ± 7	36 ± 6	35 ± 8	41 ± 8
Body mass (kg)	92.3 ± 11.9	(73.5–119.5)	83.2 ± 5.5	107.3 ± 7.9	91.0 ± 10.7	87.6 ± 11.2	87.4 ± 2.8
Height (m)	1.84 ± 0.06	(1.66–1.95)	1.80 ± 0.02	1.88 ± 0.05	1.79 ± 0.08	1.84 ± 0.05	1.85 ± 0.06
Body fat (%)	13.2 ± 3.6	(7.6–20.2)	11.1 ± 3.5	14.4 ± 4.3	13.7 ± 2.9	12.6 ± 4.2	13.9 ± 2.5
Body surface area (m^2)	2.17 ± 0.17	(1.84–2.54)	2.04 ± 0.07	2.37 ± 0.11	2.13 ± 0.16	2.11 ± 0.16	2.12 ± 0.06
Body surface area (cm^2/kg)	2.36 ± 0.12	(2.13–2.58)	2.46 ± 0.08	2.21 ± 0.07	2.35 ± 0.10	2.42 ± 0.11	2.43 ± 0.04
Maximum HR (beats/min)	187 ± 6	(177–197)	191 ± 6	186 ± 6	185 ± 7	187 ± 7	185 ± 3
Mean HR during strenuous race (4/5 intensity scale) (beats/min)	130 ± 19	(97–170)	148 ± 12	135 ± 16	128 ± 24	130 ± 12	108 ± 10

Significant different **heart rates and core temperatures** depending on the role (higher for bowmen)

Considerable sweat loss (0.9 liters/h on average) with significant differences among roles.
Bowmen suffer more from dehydration with **loss of electrolytes**; for them, it is also difficult to drink during the race due to the continuous nature of their activities.

Table 2. Heart rate and intestinal temperatures during America's Cup yacht racing

	All ($n = 23$)	*Bowmen* ($n = 4$)	*Grinders* ($n = 6$)	*Utilities* ($n = 6$)	*Trimmers* ($n = 4$)	*Afterguard* ($n = 3$)
Heart rate						
Mean (beats/min)	116 ± 18	140 ± 8*	117 ± 20	121 ± 12	108 ± 11	97 ± 12
Peak (beats/min)	160 ± 18	184 ± 10†	161 ± 19	163 ± 11	155 ± 17	142 ± 12
Intestinal temperature						
Mean (°C)	38.1 ± 0.3	38.4 ± 0.2	38.0 ± 0.2	38.1 ± 0.4	38.0 ± 0.3	37.9 ± 0.2
Peak (°C)	38.4 ± 0.4	39.1 ± 0.2‡	38.3 ± 0.3	38.3 ± 0.3	38.2 ± 0.3	38.2 ± 0.1

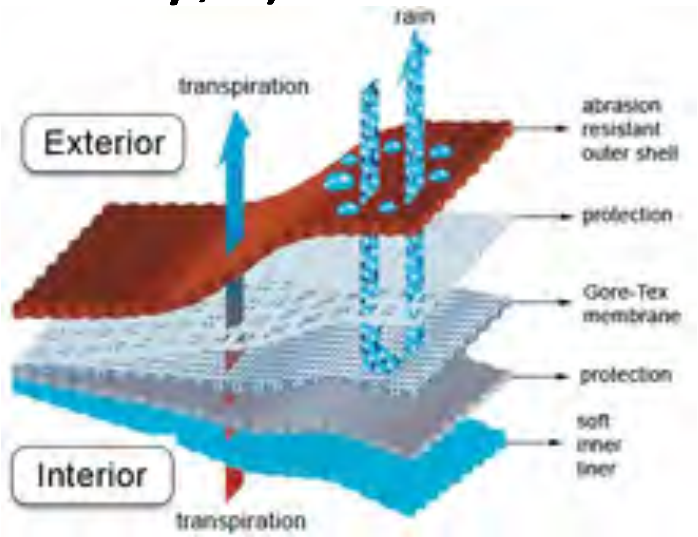
Significant differences between positions:
* *Bowmen* greater than *trimmers* and *afterguard* ($P < 0.05$);
† *Bowmen* higher than *afterguard* ($P < 0.01$);
‡ *Bowmen* higher than all other positions ($P < 0.01$).

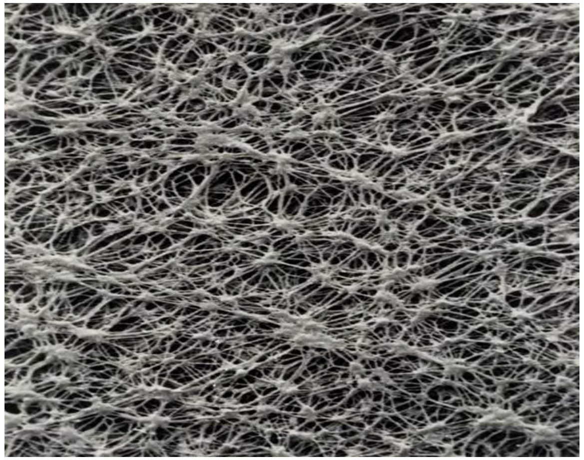
$T_c > 40°C$ RISK OF HEAT ILLNESS

- Bowmen can spend up to a third of the race below deck, with less exposure to the greater AWS and evaporative cooling of upwind sailing.
- Most bowmen wear **Goretex spray tops** to prevent getting wet, **but staying dry could be less important than staying cool (to avoid heat illness)**.
- Avoid **overdressing** while sailing upwind so that you will be cool downwind without changing garments.

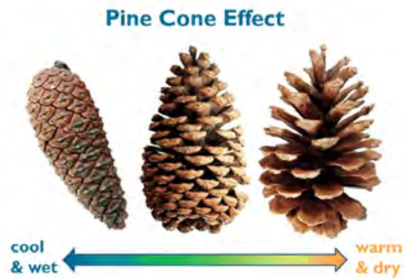
Smart textiles for convective (natural) and evaporative heat control

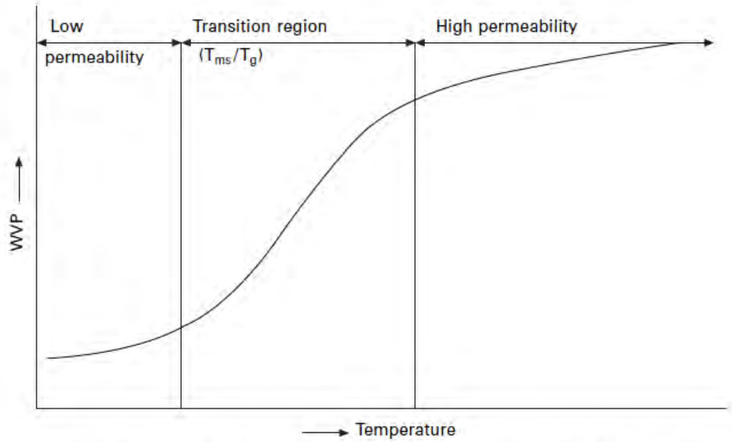
- Stimuli responsive polymers (stimuli: temperature, humidity,..)





https://www.ponoko.com/blog/how-to-make/nike-sphere





7.6 Temperature dependency water vapor permeability of shape memory polymers.

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Shape memory materials

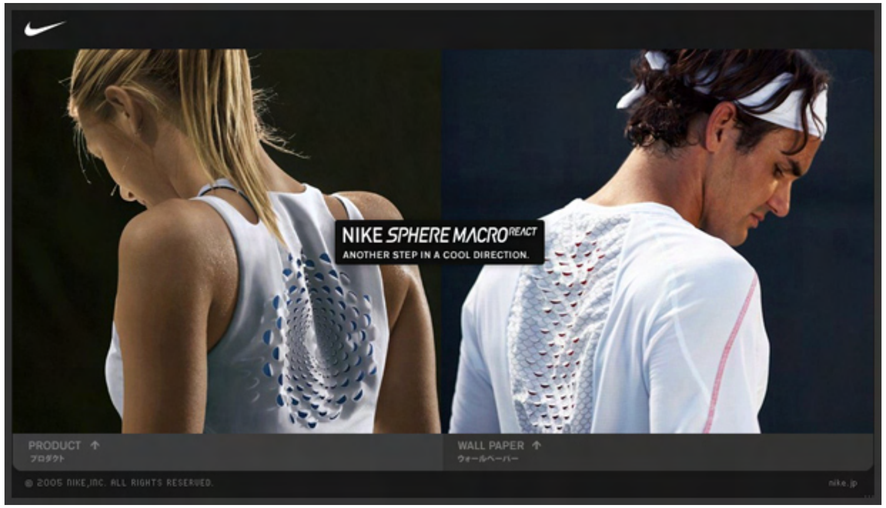
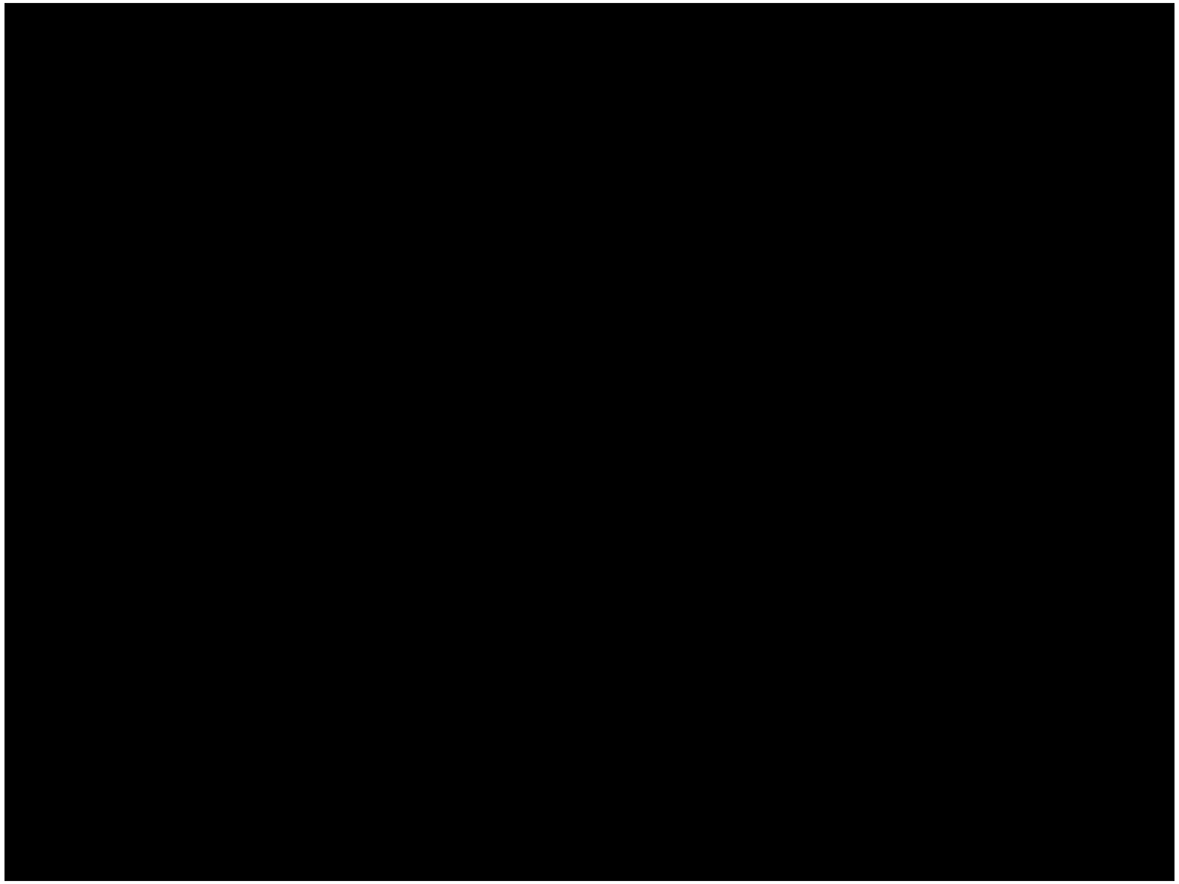


Figure 17. Back of a Nike 'Sphere React Shirt' with a smart vent structure. (Reprinted with the permission of Nike Company, www.nike.com.)

Thermosensitive garments



Different response to solar radiation, which depend on the colour of the garment

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TEMPERATURE
https://doi.org/10.1080/23328940.2018.1540964

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RESEARCH PAPER

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Thermoregulatory burden of elite sailing athletes during exercise in the heat: A pilot study

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Objective: Comparing thermoregulatory responses of elite sailing athletes in **a cool (18°C)** versus **hot environment (33°C)…**

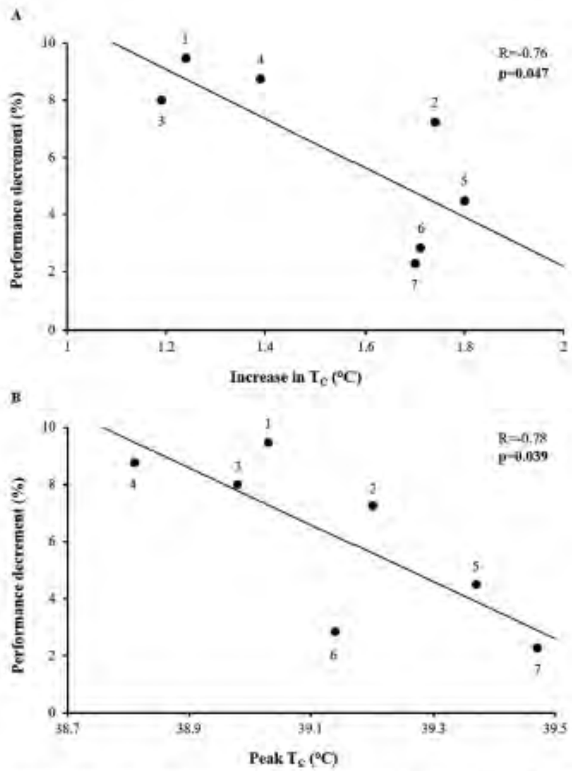
….simulating Tokyo expected conditions in a climatic chamber

Class and race-specific recommendations given by developing race specific protocols (course, activity, duration, intensity)

Wireless temperature recorders (iButton DS1922L, Dallas Semiconductor Corp, USA).

T_{SK} was measured in agreement with the International Standard Ergonomics (**Standard I.S.O. 9886, 2004**) using a 4-points measuring site consisting of left hand, right shin, right scapula, and neck

(a) (b)



Correlations between decrement in performance (%), and increase in core body temperature (a) and maximal TC (b) in the hot environment.

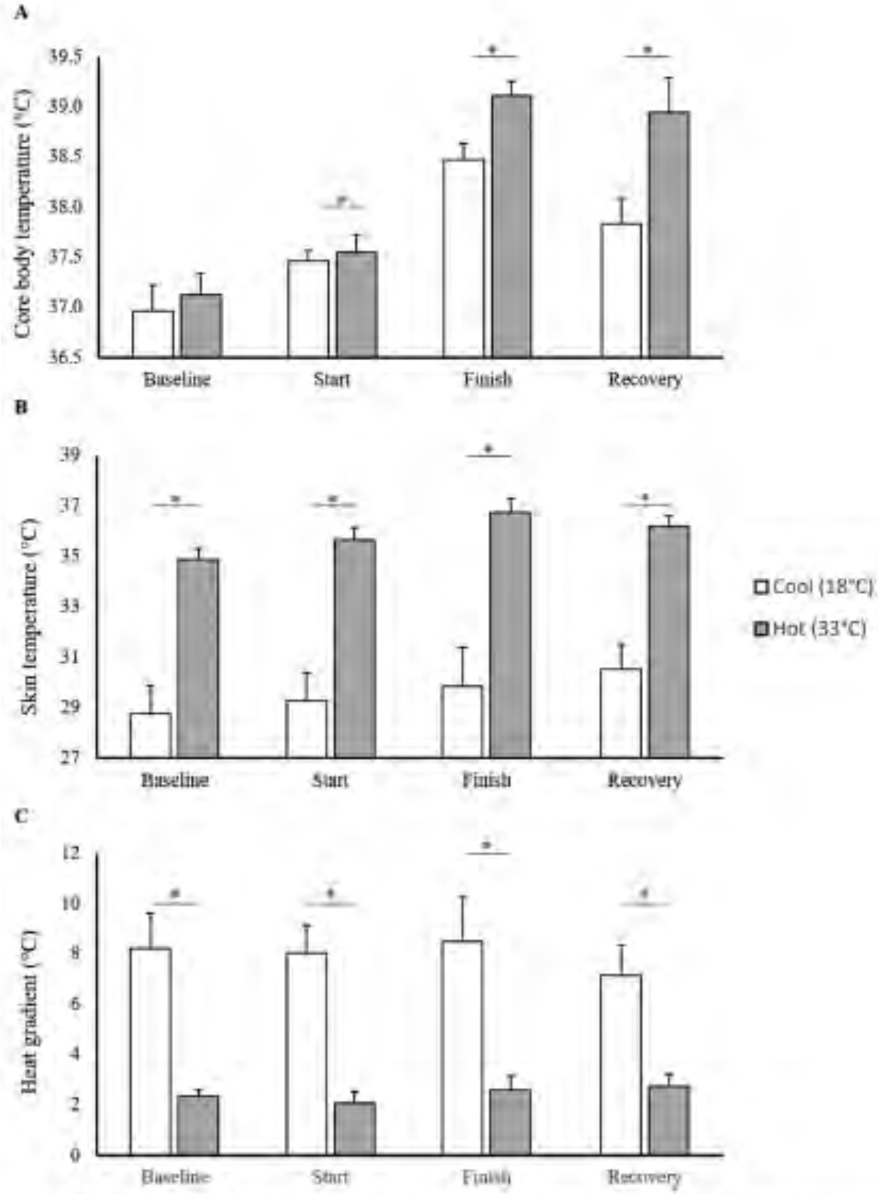


Figure 1. Core body temperature **(a)**, skin temperature **(b)**, and heat gradient **(c)** in cool (white bars) and hot environment (grey bars) at specific measurement points: baseline, start of class-specific test, finish of class-specific test and after 10 minutes of recovery. Error bars represented standard deviations, significance assumed at $p < 0.05$.

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The Effects of Continuous Hot Weather Training on Risk of Exertional Heat Illness

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[1]Biophysics and Biomedical Modeling Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA; [2]Department of Work Environment, School of Health & Environment, University of Massachusetts Lowell, Lowell, MA; and [3]Department of Preventive Medicine & Biometrics, Uniformed Services University of the Health Sciences, Bethesda, MD

MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.MSS.0000150018.90213.AA

- Wet Bulb Globe Temperature (**WBGT**) used by U.S. Army as an index for Exertional Heat Illness (**EHI**) for outdoor activities.

$$WBGT= 0.7*T_{wb}+0.2*T_{bg}+0.1*T_{db}$$

T_{wb} wet bulb temperature

T_{bg} black-globe temperature

T_{d} dry bulb temperature

- WBGT= 26.7-29.4°C
- WBGT > 32.2°C

83% of EHI occured at or below the assumed green flag level!!!

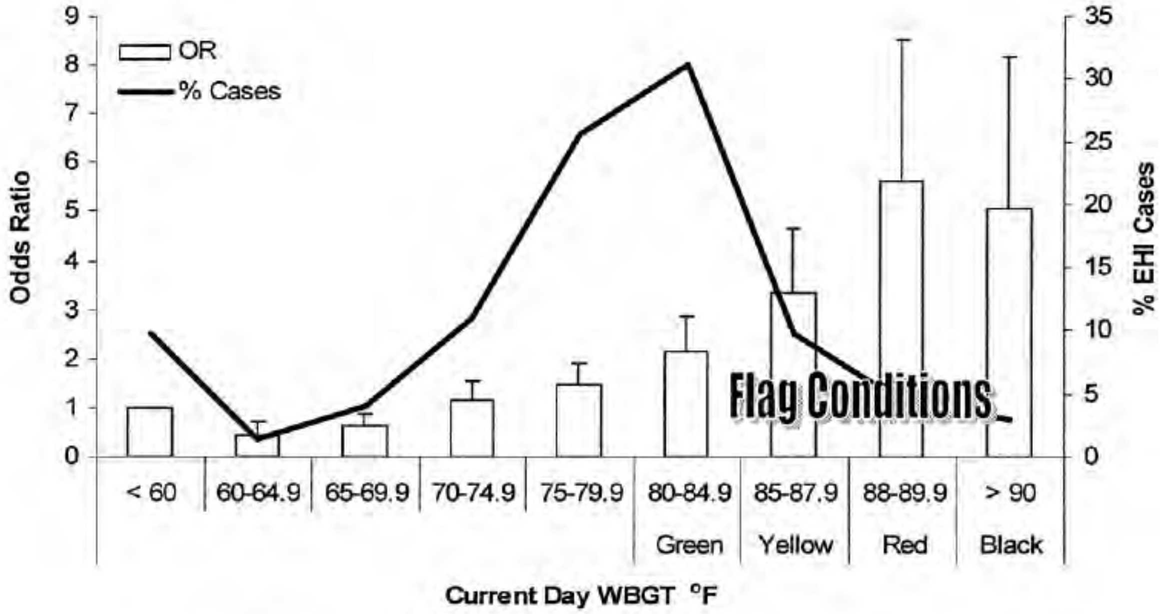

FIGURE 1—Risk of EHI by temperature conditions.

Possible cumulative effect of WBGT.

Risk of EHI was associated not only with current temperatures but with those of the **previous day** as well.

- New index (easier without the collection of black-globe temperature and wet bulb temperature)

- RHDT Relative Humidity Dry Temperature

- $RHDT=0.1*RH+0.9*T_{db}$

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MORE STRATEGIES FOR MITIGATING TERMAL STRAIN IN SAILING

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Periodizing heat acclimation in elite Laser sailors preparing for a world championship event in hot conditions

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TEMPERATURE
2016, VOL. 3, NO. 3, 437–443
http://dx.doi.org/10.1080/23328940.2016.1184367

Short-term heat acclimatization (HA) is used to prepare athletes for competition in hot environments (30-40°C)

Effects:

- Decreased resting and exercise core temperature
- Increased plasma volume
- Increased sweat rate
- Decreased heart rate for a given workload

However:

The added heat-induced stress may require a **reduction of training intensity**, while athletes often reduce training volume and increase or maintain training intensity in proximity of the competition.

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Solution:

- Short Re-acclimatization RA (1 day) after a moderate- term HA (8-14 days)
- Periodical exposure to heat following HA can allow for the retention of HA over several weeks
- Results of the **retention of HA adaptations and re-acclimatation (RA) response** for elite sailors preparing the 2013 Laser World Championship in Muscat (Oman, T≈27-30°C, 40-60% RH)

- **HA 2-3 weeks before competing, 2 additional RA sessions**
- DECREASED RATE OF PERCEIVED EXERTION (RPE), THERMAL DISCOMFORT, HEART RATE

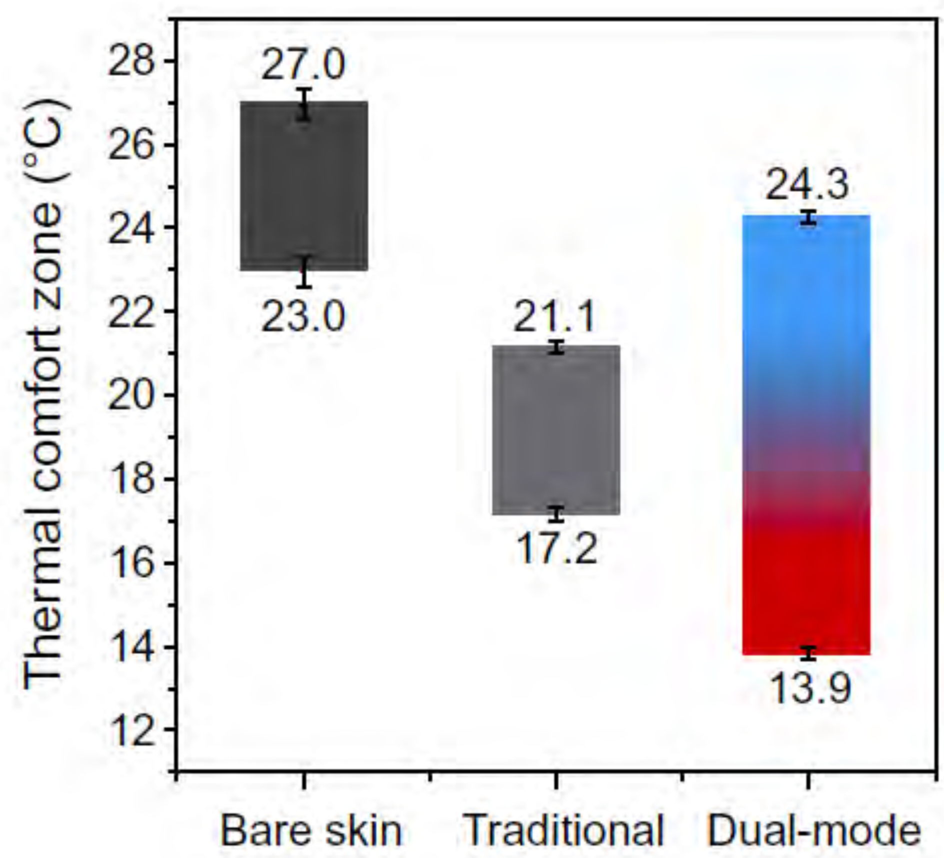
Rating of Perceived Exertion (RPE) Category Scale

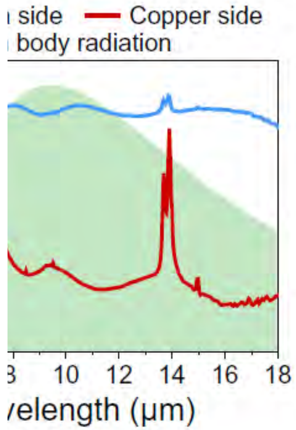
6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Borg G. Borg's Perceived Exertion and Pan Scales. *Champaign, IL: Human Kinetics, 1998.*

Smart textiles for radiative heat control

Dual-mode textile … oling using the
same piece of text…
A bilayer emitter e… olyethylene
(nanoPE) layer.





Po-Chun Hsu et al., Radiative human body cooling by nanoporous polyethylene textile, *Science* (2016) Vol. 353, Issue 6303, pp. 1019-1023

Smart textiles for convective/evaporative heat control (1)

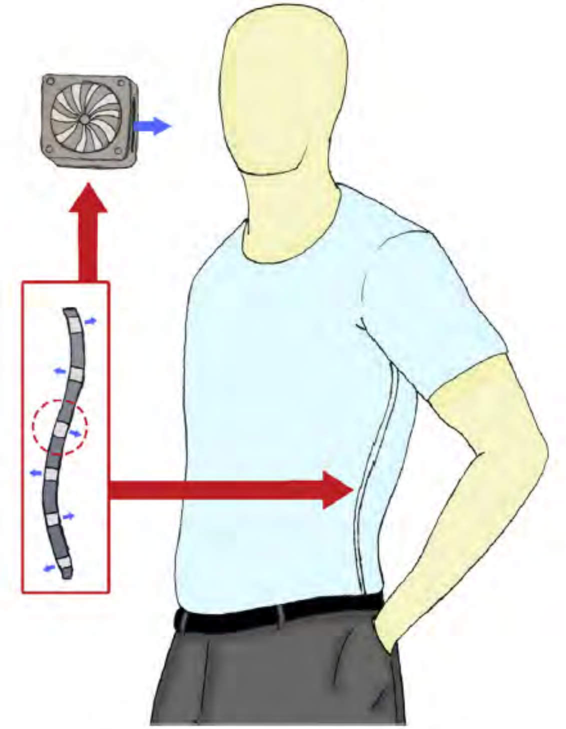
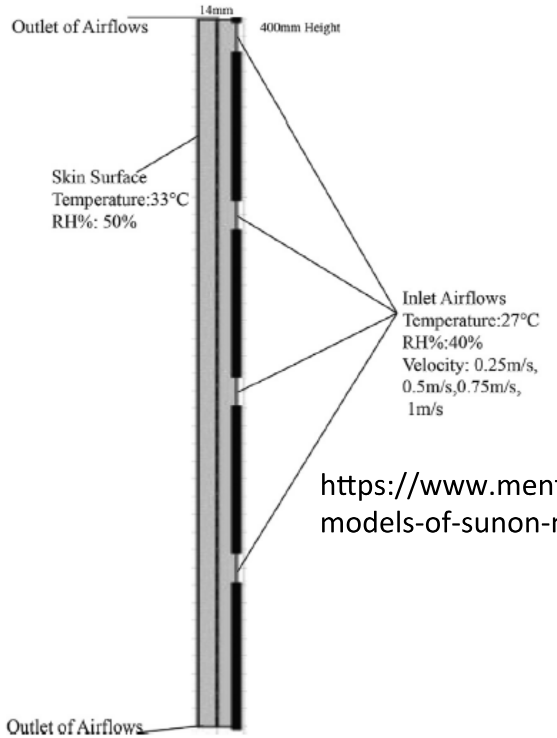
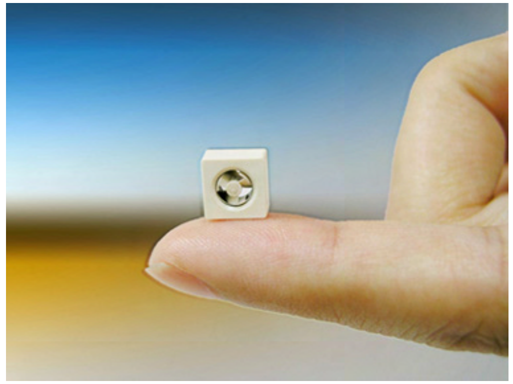


Fig. 1. Wearable convective cooling system.





https://www.mentor.com/company/news/flomerics-adds-thermal-models-of-sunon-mighty-mini-fans-to

Numerical work which optimized the thickness of the air gap and the forced air velocity for improving thermal comfort by using a commercial CFD software (COMSOL Multiphysics).

Yu Sun et al., Numerical modeling of heat and moisture transfer in a wearable convective cooling system for human comfort (2015) Building and Environment 93 pp. 50-62

Smart textiles for convective heat control (2)

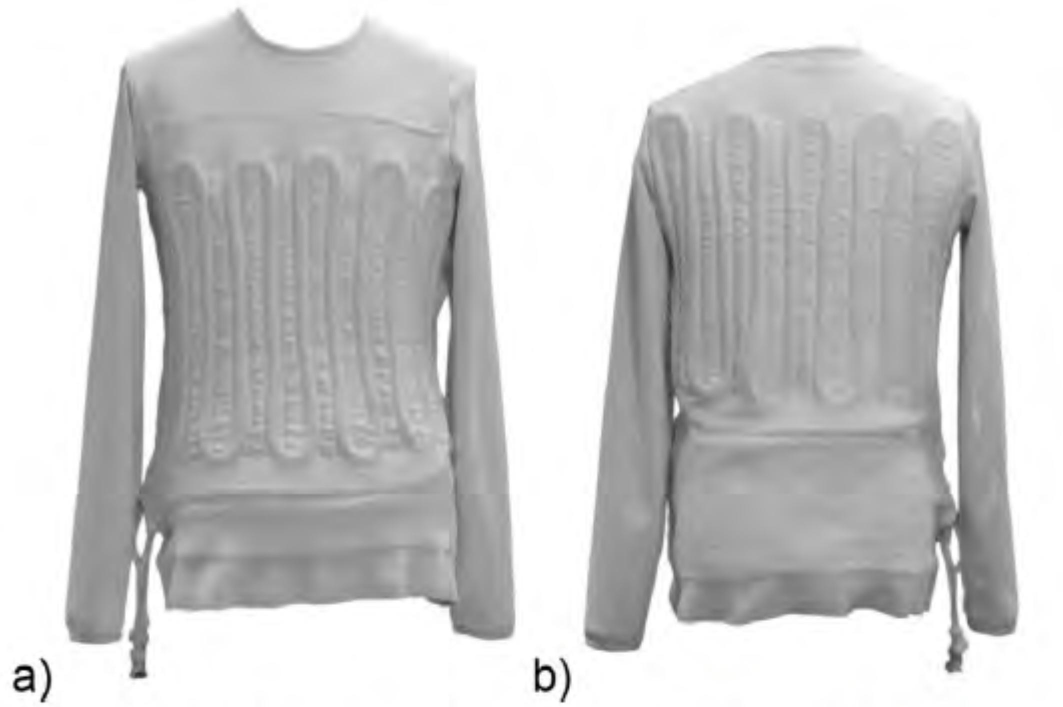


Fig. 2. Garment with a tube system distributing a cooling liquid: a) front, b) back.

The cooling unit developed to be used with the liquid cooling garment is mobile and easy to carry around by means of a wheel system. Its weight do not exceed 10 kg.

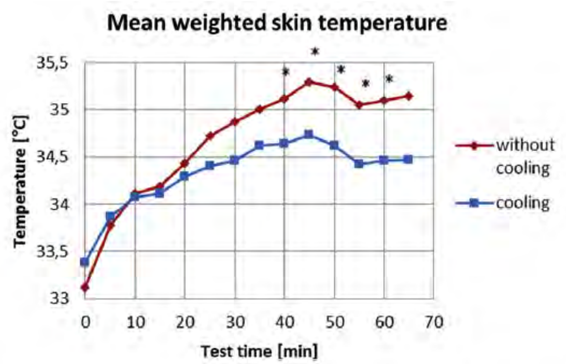


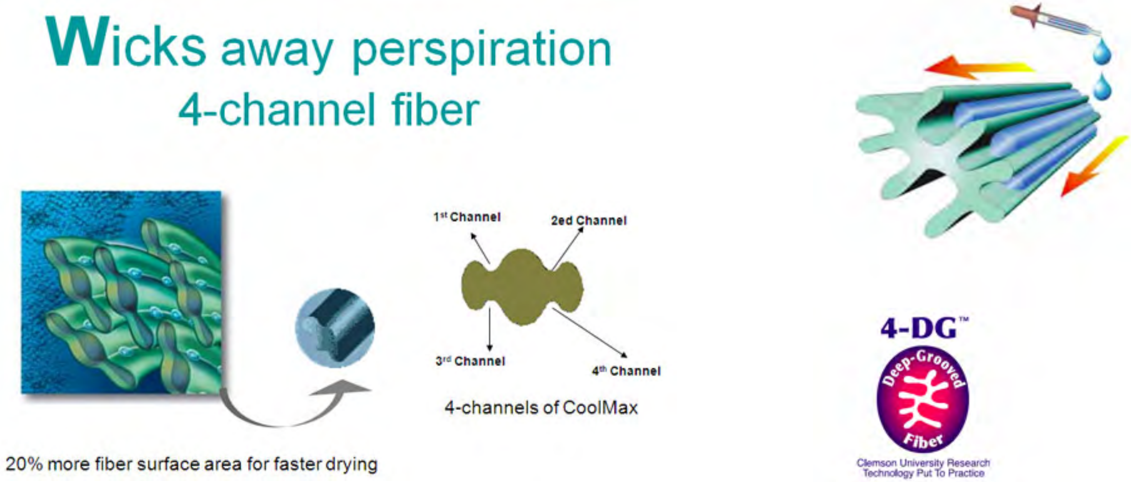
Fig. 4. Changes in mean weighted skin temperature during exercise of varied intensity.

Bartkowiak G. et al. Assessment of an active liquid cooling garment intended for use in a hot environment, Applied Ergonomics 58 (2017), 182-189

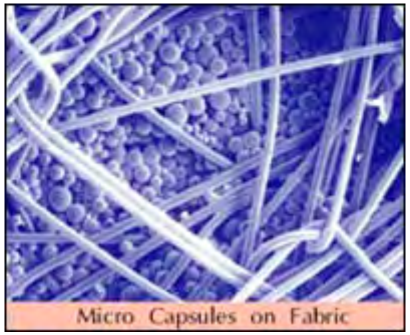
[redacted]

Smart textiles for/through evaporative heat control

- Enhancement of sweat evaporation



- Phase Change Materials (PCMs)



Inconsistencies detailing the ability of phase change materials to mitigate elevations in core temperature during exercise.

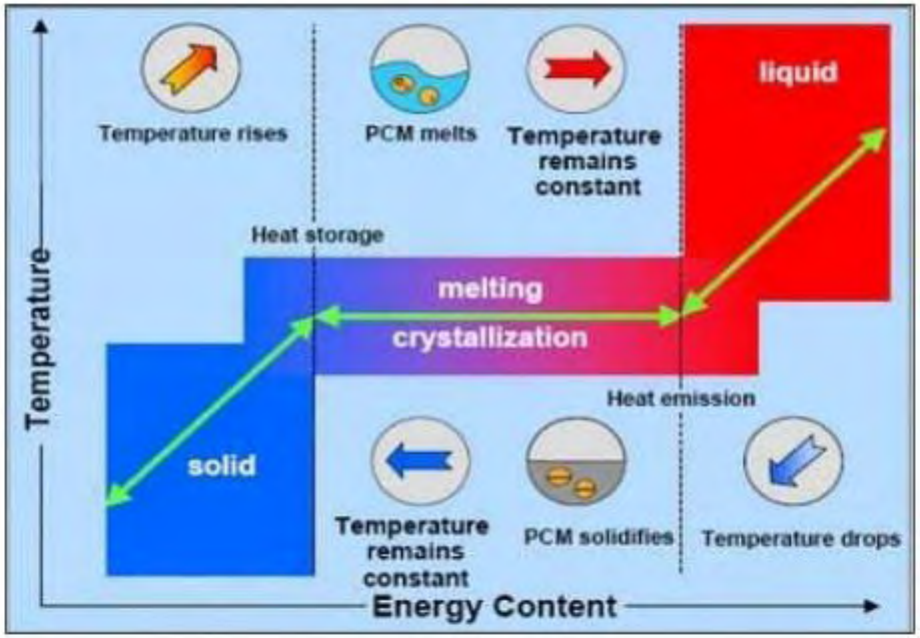
Additional mass of the phase change inserts.

Butts et al., Effects of a phase change cooling garment during exercise in the heat, European Journal of Sport Science, 2017 Vol. 17, No. 8, 1065–1073

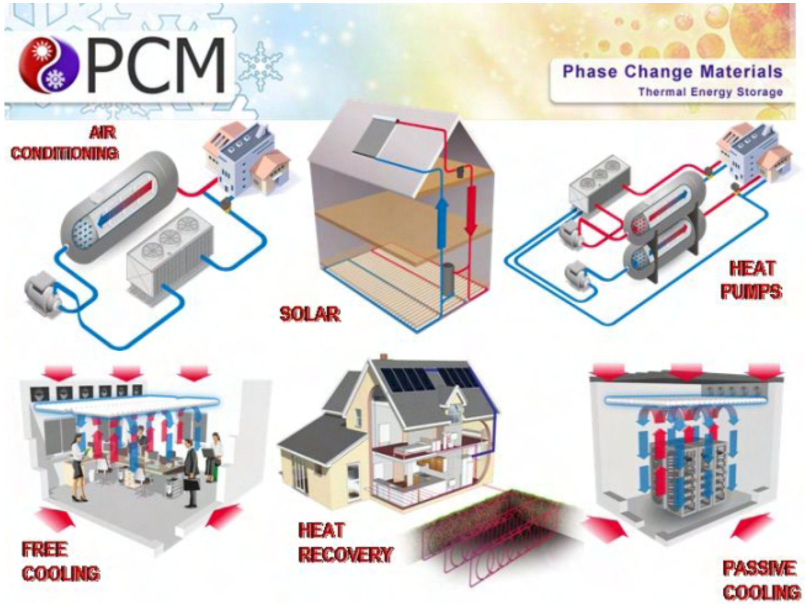
http://www.indiantextilejournal.com/articles/FAdetails.asp?id=293

PCM working principle

- Phase change materials store latent heat that has been drawn away from the skin during contact and release it when changing phase.



https://steemkr.com/science/@badet/how-phase-change-materials-pcm-works

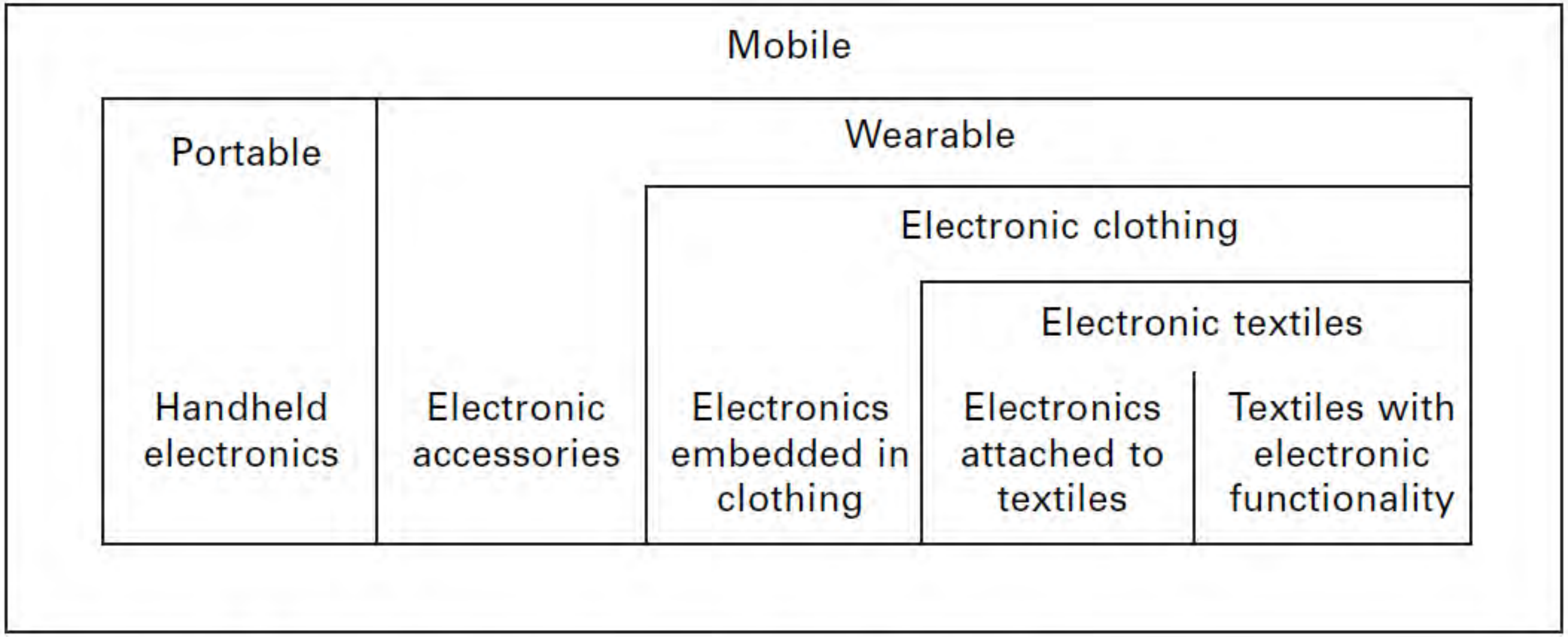


http://www.pcmproducts.net/Building_Temperature_Control.htm

Beyond thermoregulation…safety and continuos monitoring with smart textiles

Approaches

The Figure shows different approaches to on-body electronics, handheld electronics, electronics in accessories, electronics in clothing and finally electronic textiles.



21.1 Approaches to on-body electronics.

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http://www.google.com/glass/start/how-it-feels/#video=hif-video

May 28, 2013 **Apple's Tim Cook: Wearable tech is 'profoundly interesting'**

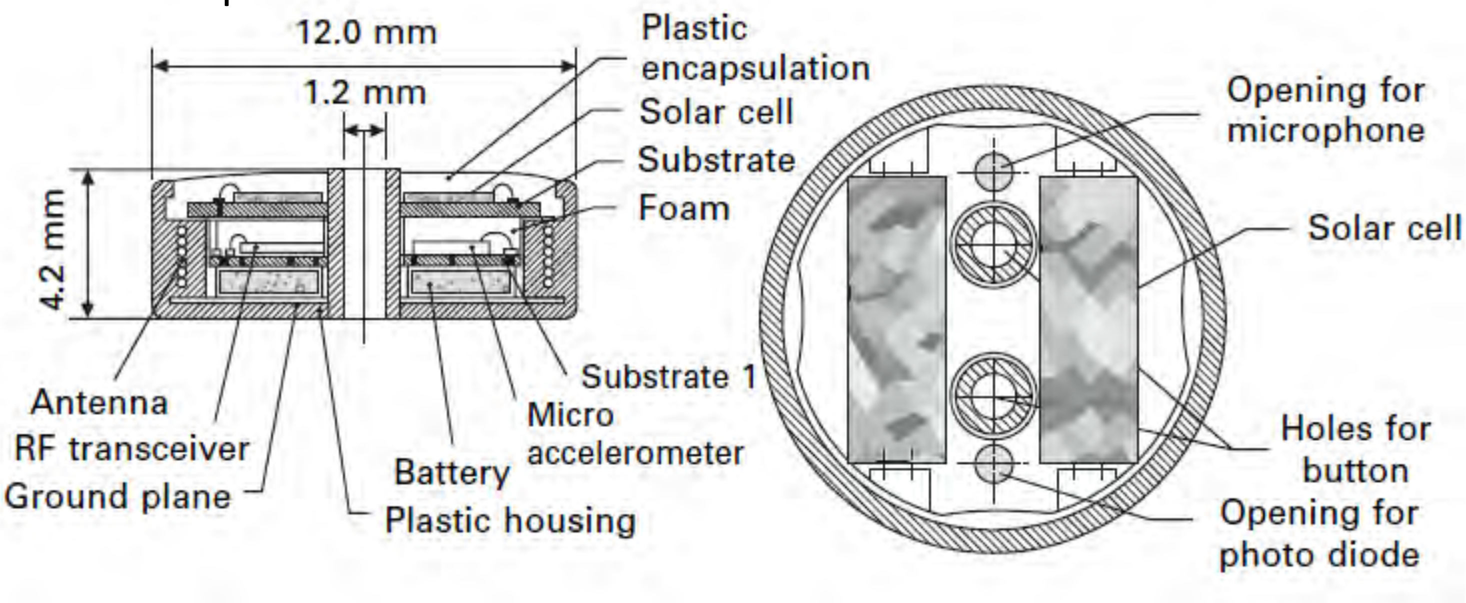
Samsung gear

State-of-the-art wearable electronics

Accessories

To foster user acceptance sensors should be small, light, and unobtrusive. **SensorButton** with the form factor of a button, so that it can be integrated in garments in an unobtrusive way. The two holes allow this system to be sewn in clothes like a normal button.

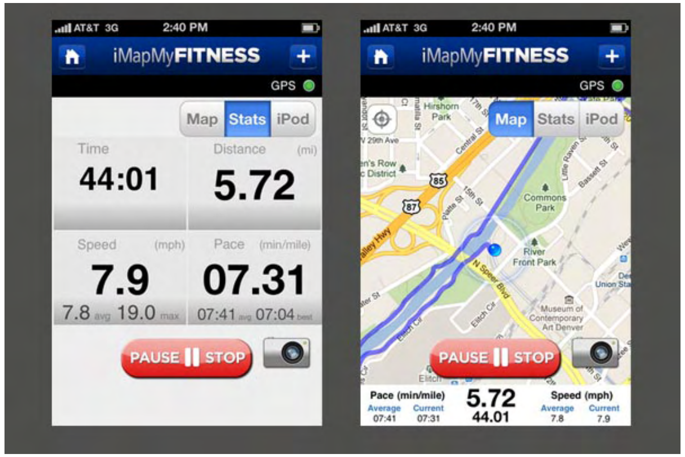
Autonomous sensor, consisting of a light sensor, a microphone, an accelerometer, a microprocessor and a RF transceiver. A solar cell powers the system even for continuous indoor operation.



New technical innovations and R&D capabilities

In 2013, US-based **Under Armour** acquired **MapMyFitness**, which utilises GPS and other advanced technologies to provide users with the ability to map, record and share their workouts.

£94 million acquisition



http://www.catalystcf.co.uk/research-documents/2014/13-global-sportswear-sector-report-spring-2014.pdf

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[redacted]

POLITECNICO
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Designing the T-shirt for the Italian Sailing Team racing in Qingdao in August 2008 for the Olympic games.

PECHINO 2008
F我V

The Team:

SLAM

POLITECNICO DI TORINO

POLITECNICO
MILANO

CLASSI OLIMPICHE

1908: la vela diventa disciplina olimpica
Sydney 2000: vengono introdotte nuove classi con equipaggio da 2-3 persone

Le classi olimpiche si suddividono per **TIPOLOGIA D'IMBARCAZIONE** e **TIPOLOGIA DI EQUIPAGGIO**:

49ER

Lungh.: 4,995 m
Equipaggio: 2 persone
MASCHILE

LASER.

Lungh.: 4,23 m
Equipaggio: 1 persona
OPEN

470

Lungh.: 4,70 m.
Equipaggio: 2 persone
MASCHILE/FEMMINILE

MISTRAL

Lungh.:3,80 m
Equipaggio: 1 persona
MASCHILE/FEMMINILE

FINN

Lungh.: 4,50 m.
Equipaggio:1 persona
MASCHILE

STAR

Lungh.:6,92 m.
Equipaggio 2 persone
MASCHILE

EUROPA

Lungh..: 3,35 m.
Equipaggio 1 persona
FEMMINILE

TORNADO

Lungh.: 6,09 m
Equipaggio: 2 persone
MASCHILE

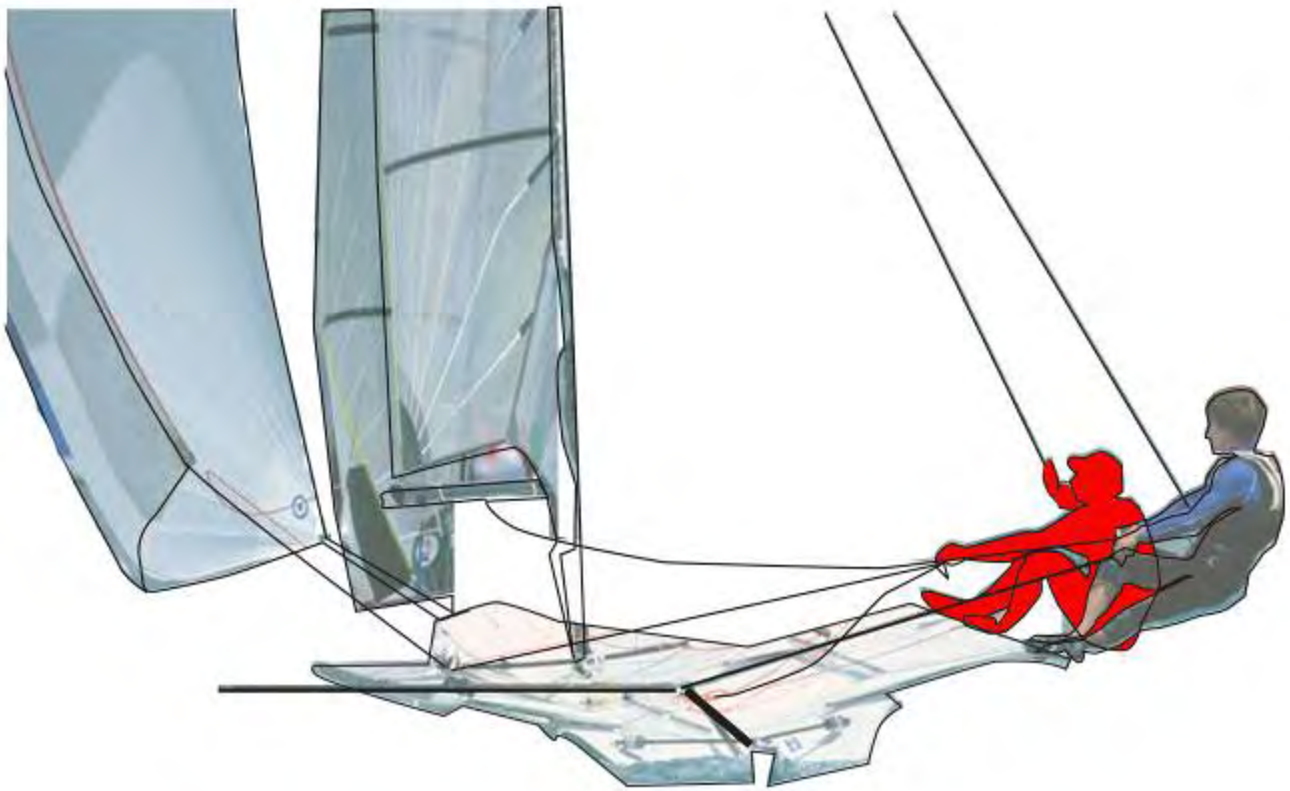
SOLING

Lungh.: 8,15 m.
Equipaggio 3 persone
MASCHILE

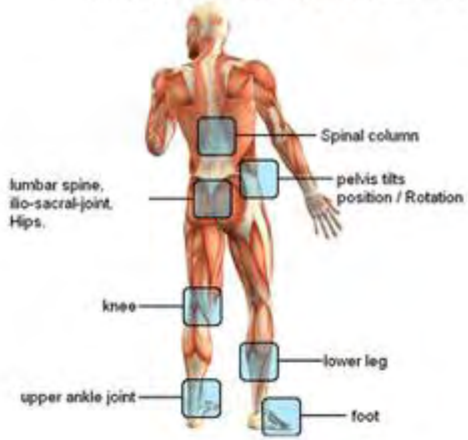
SLAM

RUOLI:

IL PRODIERE



MUSCOLI UTILIZZATI



-addominali

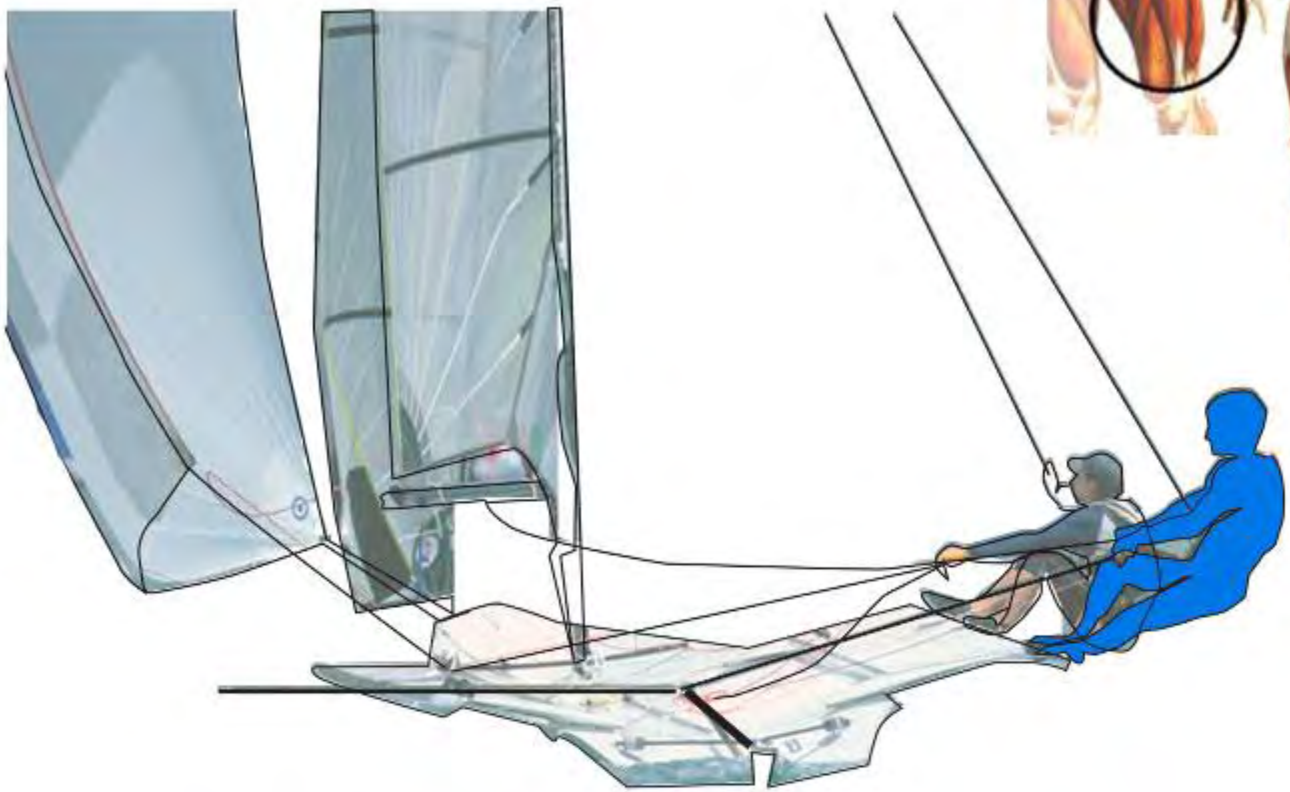
_lombari

_quadricipiti

_polpacci

_tricipiti

IL TIMONIERE



MUSCOLI UTILIZZATI

_quadricipiti

_addominali

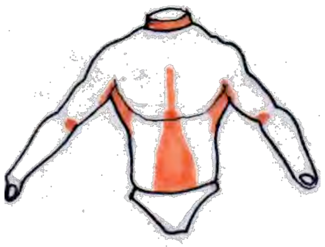
_tricipiti

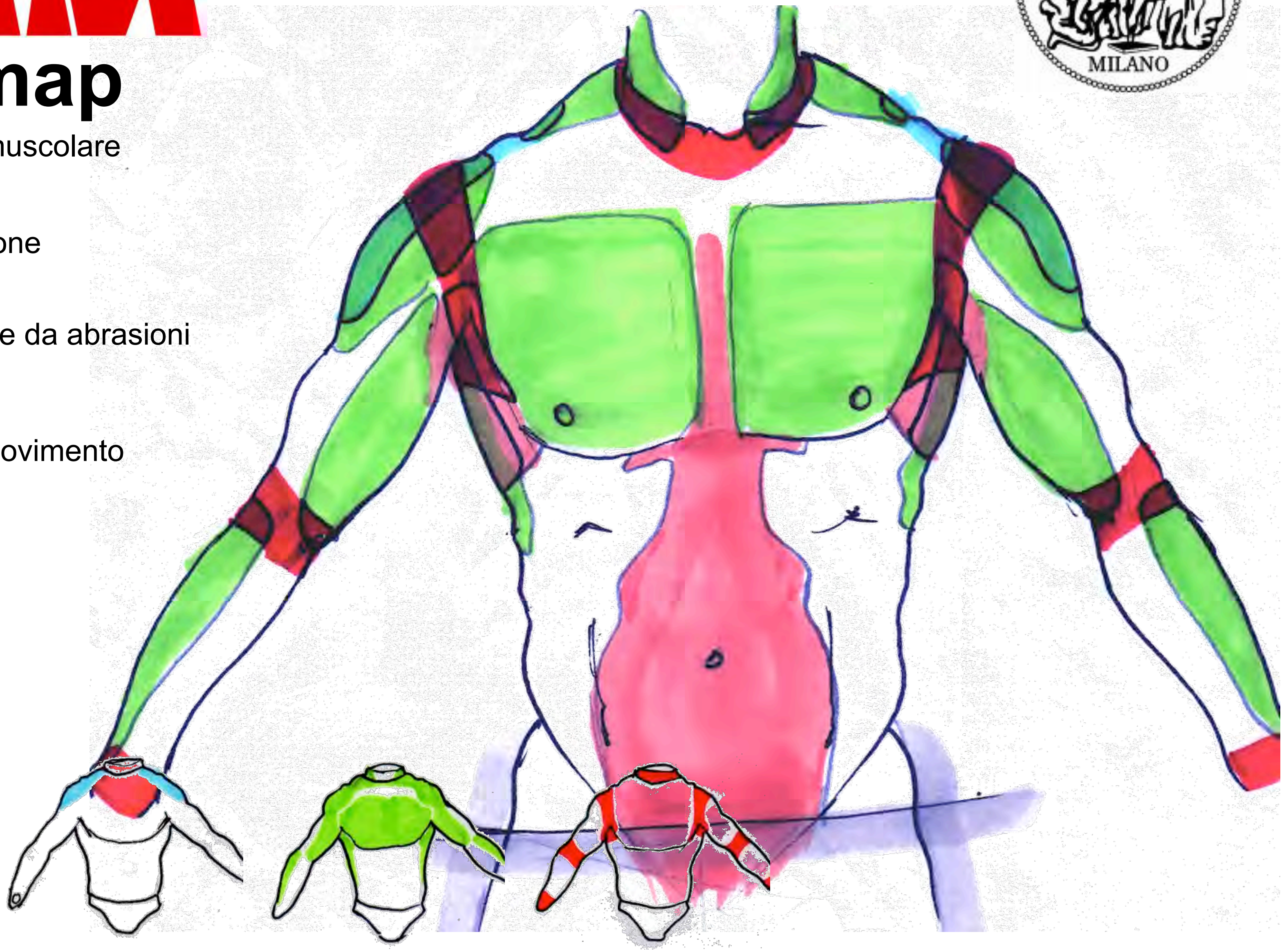
_pettorali

SLAM

Body map

- Lavoro muscolare
- Sudorazione
- Protezione da abrasioni
- Aree di movimento





Dalla body map del VELISTA alle caratteristiche del capo

■

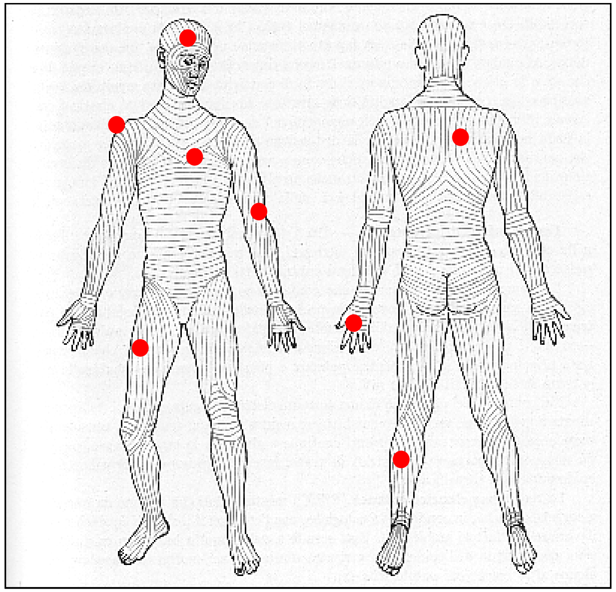
SLAM

Body map_ del VELISTA MATERIALI

- Traspirante → JL Respiro® / PP Dryarn ®
- Antiabrasivo → Cordura ®
- Termoregolante → Resistex ® Carbon
- Ergonomico → Tecnologia Seamless
- Batteriostatico → Silveraid ®
- UV Protection → Meryl ® /Poliamide

Monitored parameters

- ☑ Mean skin temperature (ISO 9886)
- ☑ Heart rate
- ☑ Vapour leaving outer surface of the fabric (at the end of the recovery period)
- ☑ Subjective evaluation of comfort

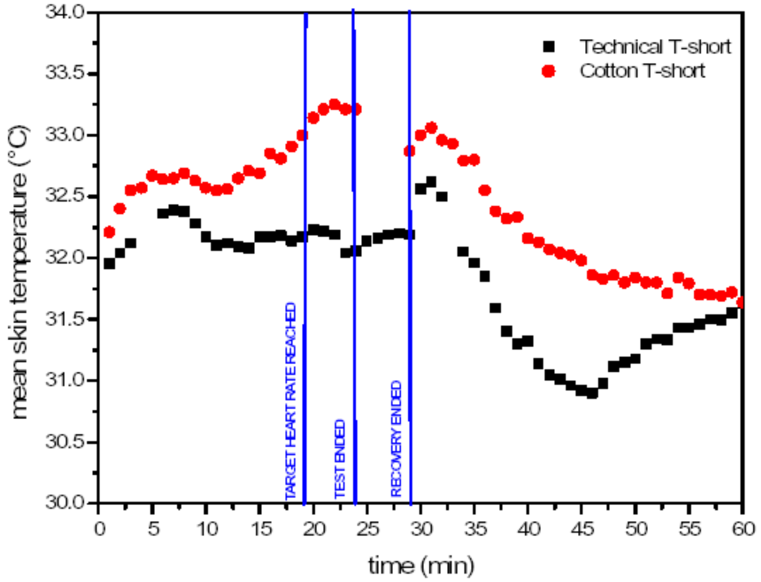


HUMIDITY SENSATION

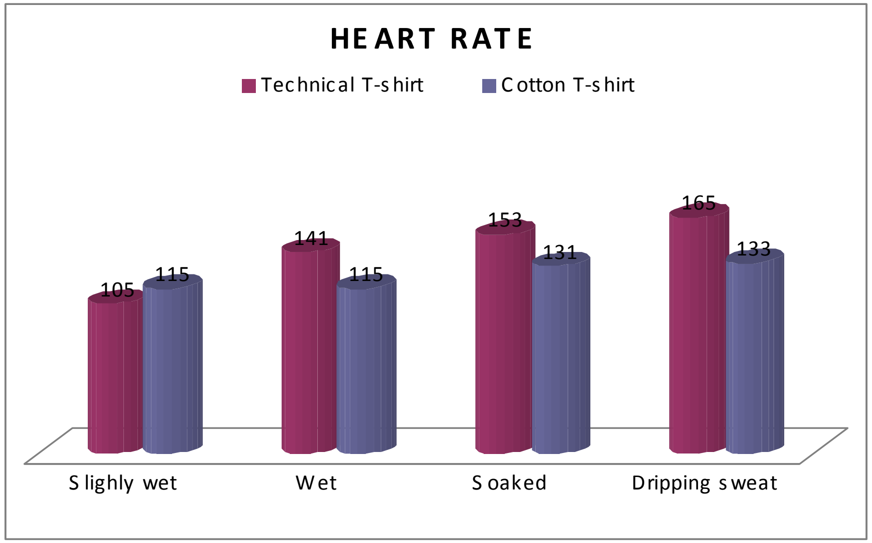
1. Dry
2. Slightly wet
3. Wet
4. Soaked
5. Dripping Sweat

THERMAL SENSATION

1. Very cold
2. Cold
3. Neutral
4. Hot
5. Very hot



Lower mean skin temperature with Area 51 T-shirt



Higher heart rate under the same humidity sensation when wearing Area 51 T-shirt

POLITECNICO
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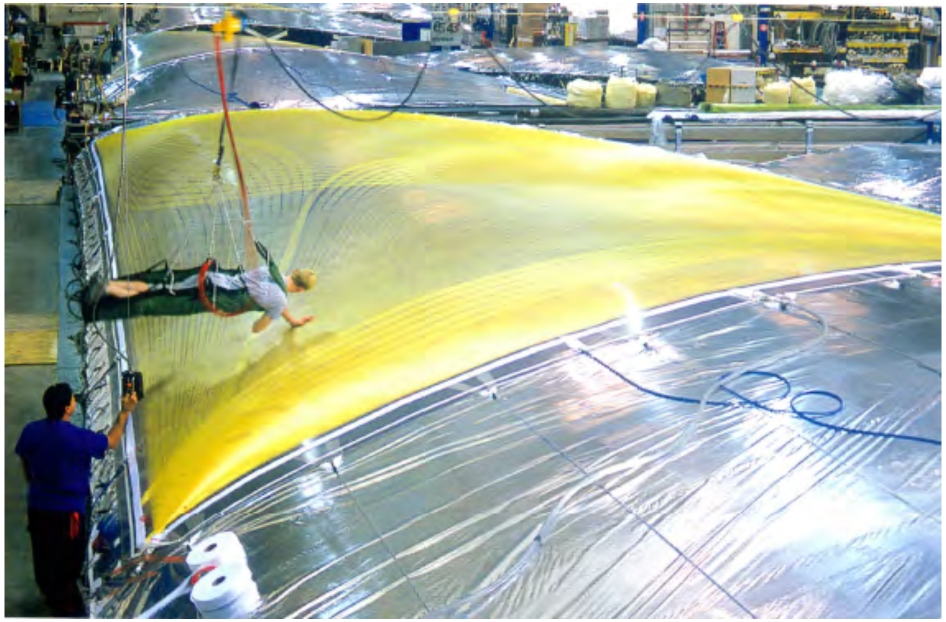
Besides garments, textiles and fibres are used in sailing for sails, ropes and hulls.



Polito Sailing Team