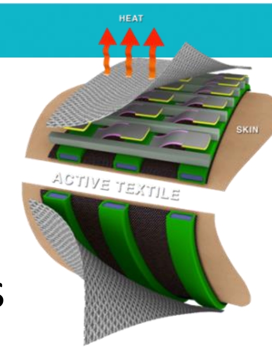
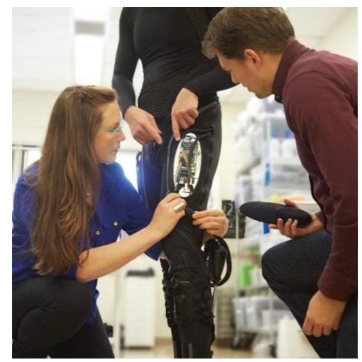
WEARABLE ACTIVE TEXTILES FOR PHYSIOLOGY-BASED THERMAL MANAGEMENT

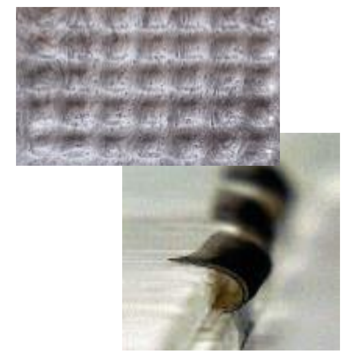


3-year Effort builds upon innovations and experience of team members

PI: Roy Kornbluh
Co-PI: Kate Witherspoon
Brian McCoy, Joe Eckerle, David Huber
T2M: Philip von Guggenberg, Michael Corbett (Consultant, GM WEEL Technologies)

- Overall **design**, integration and fabrication, Tech transfer
- **Electroactive polymer artificial muscle** for quiet and efficient pumping and porosity control
- **Soft goods, UX and T2M**

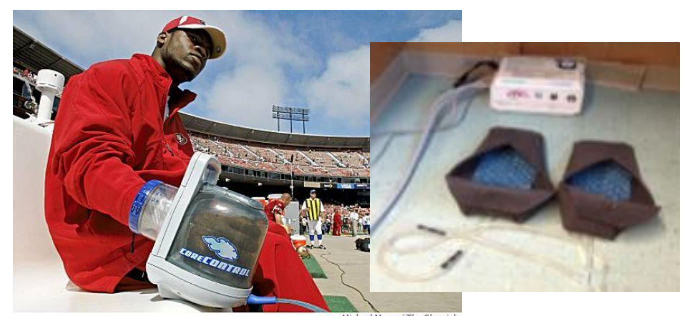




STANFORD UNIVERSITY

PI: Craig Heller
Co-PI: Dennis Grahn
Vinh Cao

- Heating/cooling requirements and control strategies, **Human subjects validation**
- **Human thermoregulation** approach

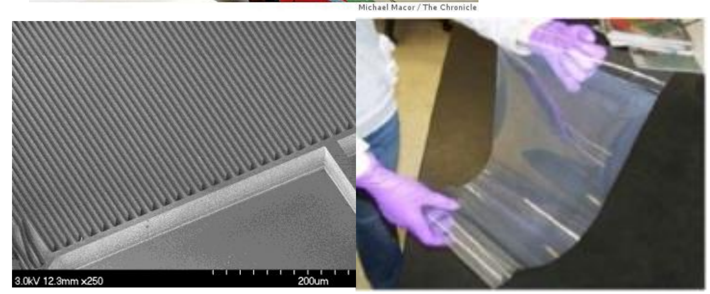


Michael Macor / The Chronicle

UCLA

PI: Qibing Pei
Co-PI: Sungtaek Ju

- Heat transfer **analysis and materials**
- **High-COP electrocaloric polymers**
- **Electroactive Polymer materials**
- **Flexible, high-thermal-conductivity materials**



Value Proposition

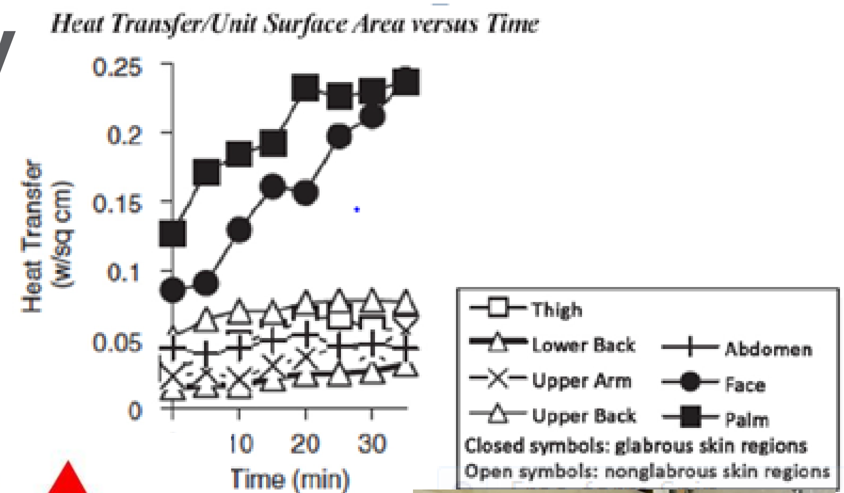
- Move the needle on energy → As common as a smartphone (useful, versatile and fashionable)
- Works with nearly all apparel → need active textile system enabled by better low-cost electroactive component technologies
  - **Lightweight** High COP heat pumping with Electrocaloric Polymer Materials
  - **Quiet** distributed pumping with Electroactive Polymer Artificial Muscle
  - **Comfortable** Conformal/Flexible heat sinks
  - **Effective** Controllability and Synergy with body's own thermoregulation
  - **Versatile and fashionable** enabling a variety of product options
- Existing approaches/technologies not sufficient
  - Thermoelectric – not efficient (COP <1), flexible or cheap
  - Phase change – logistic burden (may not reduce energy usage)and less controllable
  - Blowers – noisy, bulky

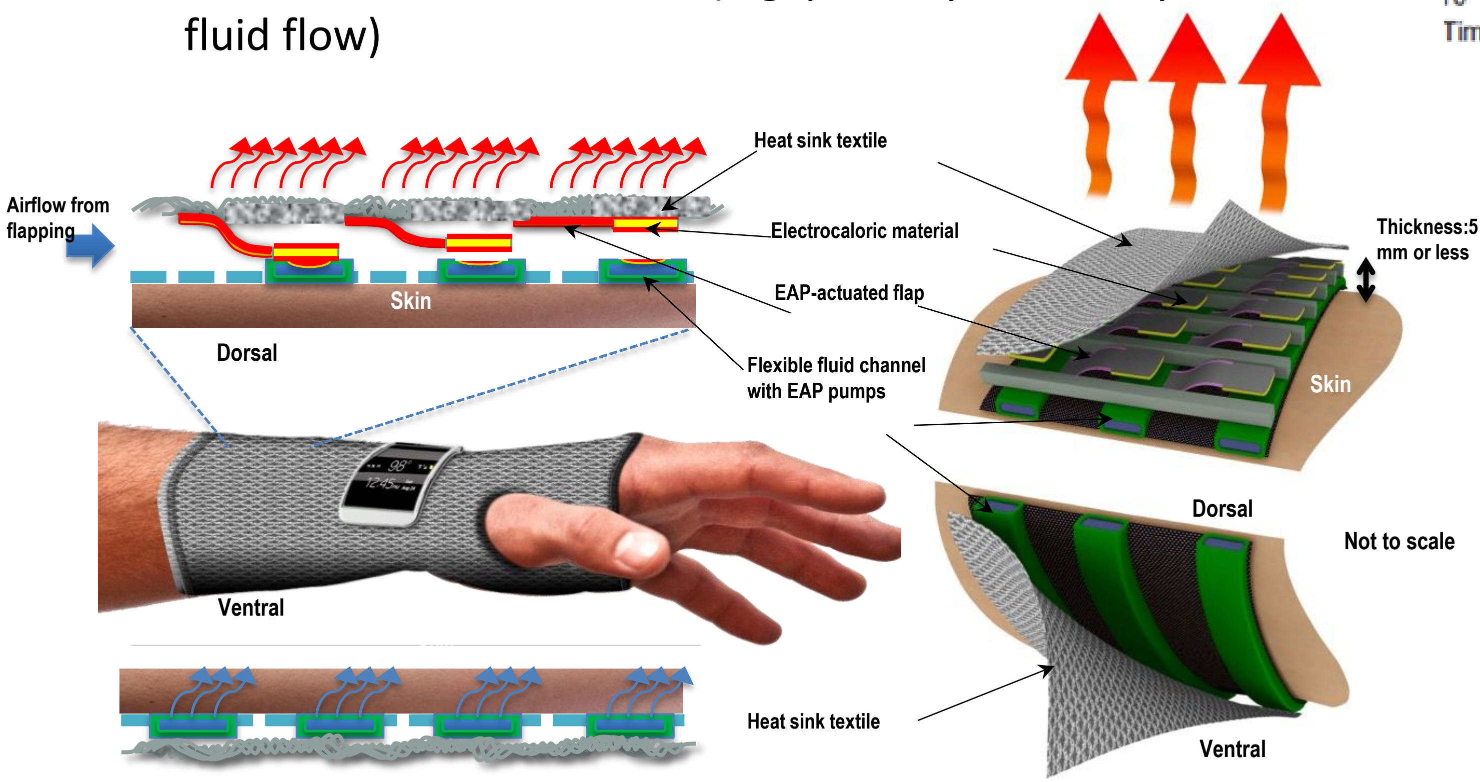
Physiology and Wearables Synergy
- Armwear or footwear inserts can exploit glabrous tissue of palms, soles or face for effective heat exchange and operate in conjunction with existing smartwatch, fitness band and bracing technologies

cool.i.am – the intersection of form and function is critical

Description of the Technology

- Active Textile "Second Skin" Uses Electroactive Technologies to Leverage the Body's Natural Thermoregulatory System
- Pivotability and Risk Mitigation
  - Tradeoffs between component performance
  - Alternate values/solutions (e.g. porosity/emissivity, fluid flow)





Stanford's successful thermal regulation approach based on understanding physiology

Metric	State of the Art	Proposed
COP (for 23 W cooling at 79^{0}F, 18 W heating at 66^{0}F)	≤1 (typical for Peltier cooling or Joule heating)	>5 cooling, >3 heating
Controllable thermal resistance	None (not electrically controllable)	>100% variation
Noise	30 dB above perception threshold (fans)	Below perception threshold

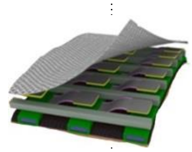
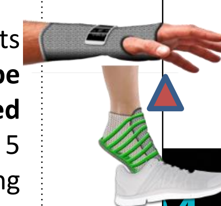
Validation Plan & Performance Targets

- Specs down to materials level derived from validated user requirements
- 3 phases (years) of system design iteration with increasing TRL and performance
- Product agnostic - multiple commercialization pathways

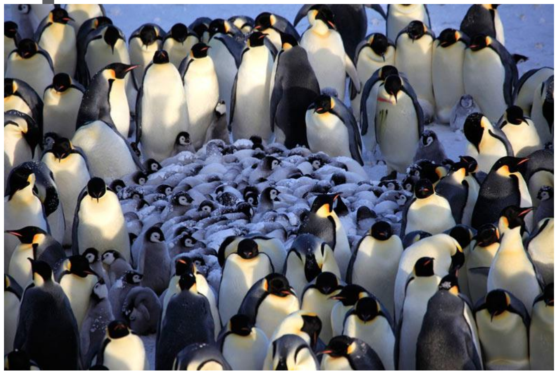
Each year of our 3-year effort:

1) **Modeling** based on human physiology to set system and component requirements and inform cost analysis
2) **Human subjects testing** to define thermal requirements for comfort and validate solutions (including user acceptance)
3) Development and characterization of component **electroactive materials**
4) Development and testing of **active textile system** (from components to subsystems to system)
5) Incorporation of user feedback to guide choice and definition of products (integrated with **T2M activities**)

User Acceptance Reqs (Stawman)	23W heat rejection; 18W heat absorption	Battery Mass: <200g; Size: 5mm x 200 sq. cm	Noise: not perceptible Comfort: 0.2 GPa, 10% strain
Materials	Electroactive Polymer: 2mm @2kPa	Electrocaloric polymer: deltaT>10K	High Thermal Conductivity material: 20 W/mK
Sub-systems	Pumping and airflow, EC actuation: 0.1 m/s	Heat pumping: 23W cooling, 18W heating	Heat spreader and heat sink: 1 K at .12 W/cm2
System	Active Textile		

Task	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Systems Integration and Testing	Testing in environmental chamber of **scalable active textile patch**; COP=2 cooling; COP=1, heating				Testing on human subjects of **wearable device**; COP=3 cooling; COP=1.5, heating				Testing on human subjects **of engineering prototype with integrated electronics**; COP = 5 cooling, COP=3, heating			

How You (DELTA Community) Can Help



- User acceptance

What will people really wear? What will they buy?

- Compare physiological models based on human subjects testing

Standardize testing?

- Modeling

What heat transfer packages are you using and what models have been developed? (Analogy to OpenSim for biomechanics modeling?)

- Measurements

What sensors, equipment and procedures have you found to be most effective for thermal and fluid flow measurements? Emissivity?

- Materials

Existing high thermal-conductivity textiles?
Better batteries or wireless charging?

- Multi-purpose

Synergy with medical, athletic, outdoor and humanitarian needs

- Sharing

What can we do for you? (electroactive materials, Human Subjects Testing, ?)