UC San Diego Institute for Public Health: 2017 Pilot Grant Submission

January 23, 2017

Title: Improving the cost-effectiveness of wearable biosensors for environmental health studies

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1. Specific Aims

Heat-related mortality is one of the greatest causes of death due to weather extremes (Berko et al. 2014), and heat-related illness is a significant concern for public health agencies, emergency responders, and hospitals (Bernard and McGeehin 2004; Klinenberg 2015). Ambient exposures to temperature, ultraviolet and global radiation, and humidity may change rapidly in heterogeneous urban environments and are tightly connected to physiological responses to heat. The expansion of urban areas and climate change culminate to increase future human heat exposures (McCarthy and Sanderson 2011), specifically impacting children's health (e.g., Sheffield and Ebi 2013). As compared to adults, children have higher body surface area to mass ratio, higher heat production per unit body mass, and a higher proportion of cardiac output delivered to skin under heat stress. Although children are at greater risk, there is a paucity of epidemiological data that associates these risk factors with injury rates (Falk and Dotan 2008).

The acceleration of physiological sensing technologies offers a vast opportunity to improve our understanding of the association between children exposures and their physiological responses to these environmental variables. Specifically, our development of flexible, thin, stretchable "tattoo" sensors (Kim et al. 2011) represents the next generation of wearable technologies and opens new opportunities in exposure science. However, limitations in fabrication time and cost exist in obtaining large, robust, and effective sample sizes. By building upon our recent microfabrication innovations that are compatible with industry-adopted techniques (Kim et al. *in review*; Kang et al. 2015), we plan to develop a modularized adhesive-integrated flexible electronic system consisting of disposable sensors (for body temperature, UV radiation, and cardiac activity), a reusable integrated circuit for wireless transmission, and a reusable flexible battery. This system will have immense potential to enable ambulatory low-cost monitoring of physiologic responses to extreme heat in vulnerable populations.

The sensors will be validated in the field both for performance after modularization and the ability to accurately measure variables connected to children's heat exposure-response, and thus provide new information on understanding's children heat-health. The feasibility of our proposed activity is supported by the clinical success of the tattoo sensors to monitor vital signs, and that the battery and circuits can be detached from the sensors and be reused, rather than disposed of. Further, the current sensor systems designed in Co-I Coleman's lab are proven to provide accurate information on the heat-health biomarkers of skin temperature, heart rate, and galvanic skin response (Kim et al. 2011; Harbert et al. 2013; Kang et al. 2015), and can be augmented with UV-responsive sensors through similar methodologies. The proposed methodology will result in the ability to complete larger ambulatory studies with the sensors that are feasible for research, which will provide fundamental insight into the validity of the sensors for understanding children's heat health.

Aim 1 will develop an improved fabrication methodology to create a sensor system consisting of three modules, rather than one, and further augment the current system with a UV sensor. The current sensors will be separated into three components (i.e., separate sensors/circuits, active electronics, and a separate battery) so that the battery and active electronics can be reused. A new UV-sensitive polymer layer will also be embedded into the current sensor system. This aim will result in the ability to build the sensors for $10 as opposed to $85, thus creating the possibility for feasible, large scale ambulatory exposure studies in a non-invasive manner.

Aim 2 will validate the measurements of UV radiation and core body temperature from the sensor systems. Accurate measurements of ambient UV levels and children's core temperature will be taken during physical activity in a children's playground for validation of the tattoo sensors. Body core temperatures will be estimated using heat balance modeling (Vanos et al. 2012a) and novel statistical techniques by Buller et al. (2010) using heart rate measurements. These validations will address the problems of obtaining true UV-exposures in a child population, and in accurately estimating the most important parameter in predicting hyperthermia—human core temperature—from non-invasive wearable sensors.

In utilizing the flexible skin sensors, we can complete physiological exposure assessments never before possible on children's population, a population vulnerable to heat exposures. Our approach is designed to capitalize on existing technologies and improve their use through cost reduction and miniaturization so that larger population studies in environmental health research can be performed by researchers at UCSD locally, nationally, and internationally, and thus pursue new research and applications that have not previously been possible due to scaling limitations. The proposed research is also unique in addressing the three key themes of the Institute for Public Health. First, we focus on the improvement and application of novel technology for advancement applications in public health. Second, we enhance the ability to monitor real-time exposures that affect well-being in a vulnerable population. Finally, we focus on physiological responses connected to temperature, increases which are the main indicator of climate change.

2. Background and significance

The implication of lessening heat and radiation exposures in playgrounds may help reduce direct heat illness in children (Knowlton et al. 2009; Rhea et al. 2012), obesity due to a decrease in activity with high temperatures (Saha et al. 2005), burns from hot surfaces (Vanos et al. 2016), ultraviolet (UV) sunburns (Downs and Parisi 2012), and exacerbation of asthma symptoms (Hayes et al. 2012; Xu et al. 2013). Even with such knowledge, the ability to model the heat balance of children during exercise has received little attention, accounting for less than 10% of 1200 published articles before 2006 (Falk and Dotan 2008). A main reason that a solution to understanding children's thermoregulation in outdoor spaces is currently missing is due to traditional invasive techniques that are commonly used in a lab, such as rectal or esophageal thermometers, which are not suitable for children during play. To address these two issues, we employ non-invasive, flexible, and miniaturized sensors technologies ('tattoo sensors') to monitor and record real-time responses to acute responses in intermediate heat-health biomarkers in a safe manner. As core temperature (T_c) is one of the key diagnostic determinants of overexposure to heat (Casa et al. 2007), there is significance in providing improved estimations of through non-invasive means. Researchers are actively looking for ways to develop algorithms based on environmental and/or easily obtained physiological variables for accurate T_c prediction (e.g., Chan et al. 2001; Buller et al. 2010; Hensley et al. 2013). Prediction of T_c has significance for lessening heat illness and death due to heat waves (Chan et al. 2001), exertional heat stress (Armstrong et al. 2007; Casa et al. 2012), and for urban climate adaptive designs to reduce health impacts and improve well-being (Georgescu et al. 2014; Vanos 2015). With such information, we can move from the notion of simply predicting a hot environment/hot day (or heat wave) to predicting (and preventing) hyperthermia events.

The advancements in wireless instrumentation across spectrums, such as climate and health, transforms the way in which such researchers can obtain and provide effective, real-world solutions. Co-I Coleman's research has made meaningful advancements in demonstrating that the best way to understand vital signs related to exposures or ailments is to monitor in natural, real-world settings with devices that are invisible to the user (Kim et al. 2011). The future of sophisticated sensing technology will increasingly involve miniaturized sensors providing robust measurements of children's vital signs; hence, vast potential for future studies is expected to arise from the proposed research.

3. Preliminary Data

3.1 Flexible, stretchable electrical sensors

Work by Co-I Coleman has demonstrated success in integrating the flexible, stretchable electrical sensors, circuits, and antennas inside of materials that naturally interface with the human body (Kim et al. 2011). Specifically, these adhesive-integrated systems are flexible, stretchable sensors that can monitor respiration, electrocardiogram (EKG), galvanic skin response, and skin temperature (Figure 1). Each system costs $85 for 24hr use. Such costs can be inhibitive in a research project requiring large populations. In recent years, Co-I Coleman has led scalable fabrication and integration methods for the flexible electronics. The fabrication methods to enable these sensors are simpler than previous methods, obviating the need for steps that are error-prone and expensive, and are compatible with roll-to-roll type processing to enable economies of scale (Kang et al. 2015). In addition, novel fabrication methods compatible with industrial processes have been developed to embed integrated circuits for signal processing and Bluetooth transmission into flexible adhesives (Kim et al. *in review*).

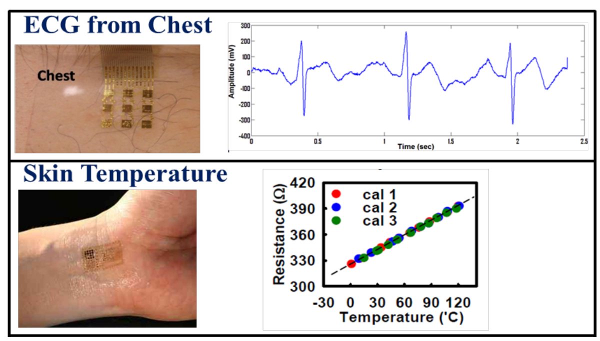

Figure 1: Flexible electronic sensors embedded inside of a temporary tattoo capable of measuring EKG as well as skin temperature (Kim et al 2011).

3.2 Children's Radiation Exposure and Thermal Balance During Active Play

A field study was lead by PI Vanos in the spring of 2016 monitoring microclimatic variables along with the heart rate, acceleromtery, and erythemally-weighted UVR (UV_{Ery}) of 14 children. This took place in a playground in Lubbock, TX, and examine children's heat balance and UV_{Ery} variability during physical activity. Accurate assessments of personal outdoor exposure to UV_{Ery}—specifically—is a challenge due to technological constraints, variable time-activity patterns, and the influence of outdoor design. Through utilizing mobile personal dosimeters (Figure 2), and stationary high-end pyranometers, results demonstrated 1) movement due to physical activity caused significantly under-prediction in ambient UV_{Ery} exposures, and shade provided a meaningful reduction of 55% in the personal UV_{Ery} exposures, $UVB_{280–315nm}$ exposures by 91%, and the overall

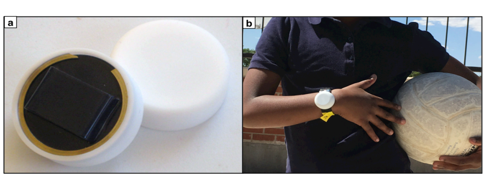

Figure 2: UV dosimeters (a) to be worn on children's wrist (b) (Vanos et al. 2017).

solar radiation by 84%. Heart rate (HR) and accelerometry were applied to children's heat balance monitoring to quantify energy expenditure and activity speed in the COMFA model for quantifying skin and core temperatures (Figure 3) and heat balance (Vanos et al. *in review*). We determined that substantial benefits can be garnered through focused design of children's recreational space to utilize shade, both natural and artificial, to reduce UV_{Ery} and heat exposures during play, and to extend safe outdoor stays.

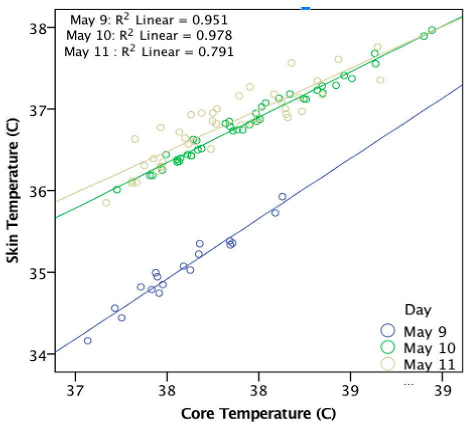

Figure 3: Heat balance modeling of core and skin temperature relationships during play for 14 children, May 2016 (Vanos et al. *in review*).

4. Research Design and Methods

Heat tolerance—defined as the ability of the body to maintain a safe core temperature—is both the reason for and the result of thermoregulation (Falk and Dotan 2008), based on a combination of physiological and environmental variables. An intricate balance sets up between the human body and the ambient environment during physical activity in extreme heat, and this balance between energy gains and losses is properly understood only when both the environment and human responses are quantified. Currently, PI Vanos is focused on quantifying personal ambient exposures in children connected to thermoregulatory responses in outdoor spaces and is working with Co-I Todd Coleman and his research group to devise new methods to monitor these environmental components with wearable sensors in children. The research approach is designed to provide preliminary information useful for submissions to large funding agencies in addition to furthering the applicability of the sensors in research meaningful to public health and climate impacts. Using a convergent and systems engineering perspective that treats the human body as a system, we will be able to understand the interconnected responses during outdoor physical activity in children.

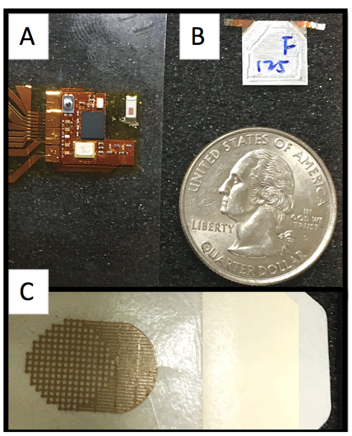

Figure 4: Three modules of the sensor system. A: active electronics, B: battery, C: sensor, versus size of quarter. In the new system, A and B will be reusable, C will be disposed.

Aim 1 will focus on adapting the sensors from one integrated module into a system with separate sensors, integrated circuits, and battery. Scalability will be improved by designing and building a new adhesive-integrated system in a modularized fashion, with disposable and inexpensive flexible sensors, reusable integrated circuits (active electronics), and a reusable battery, thus significantly reducing costs (see Figure 4). Module A, containing integrated circuits signal processing and encoding for wireless transmission, includes a programmable Bluetooth system-on-a-chip and all circuits. It has been fabricated successfully by Co-I Coleman's group at UCSD on a flexible substrate using methods in (Kim et al. *in review*). Preliminary tests showcase that it successfully transmits data via Bluetooth to the phone. Module B corresponds to a flexible, rechargeable battery from Frontedge Technology (http://www.frontedgetechnology.com/gen.htm). At a thickness of merely 100μm, the battery is of the same approximate thickness as the adhesive. Module C corresponds to a disposable adhesive-integrated flexible sensor that provides intimate, mechanically undetectable skin integration. Fabrication methods developed by Co-I Coleman's group, described in Kang et al. (2015), will be employed. The modularization drastically reduces costs as the disposable sensors are $10, rendering the aggregate system an order of magnitude less costly than previous.

The main innovations will be (i) the optimization of the electrical interconnection of modules A, B, and C with microfabrication methods as well as (ii) the incorporation of a UV sensor. For (i), one of the key advantages of our method for manufacturing stretchable electronics is the compartmentalization of each step. While the lamination of the off-the-shelf adhesive dressing (e.g., 3M Tegaderm™) provides an easy way to integrate sensors with active electronics, other packaging techniques such as drop-casting and spray-coating, can enable efficient packaging of devices as well as complete encapsulation of the active electronics.

As for (ii), the aforementioned packaging material will also acquire UV-sensing functionality by mixing a polymer system that responds to UV light based on a change in color (Lee and Armani 2016), or level of optical transmission (Kim et al. 2016). The modulation in optical transmission and its corresponding UV dosage (*UVEry*) will be accurately determined by employing an optoelectronics system demonstrated by Kim et al. (2016). In this system, a single photodetector—a red and infrared LED—are used to calculate the level of total UV exposure by comparing the ratio of transmission levels between the two LEDs. Since all electronic components within this technology are also off-the-shelf and reflow-solderable, there is good compatibility with our current manufacturing method (Kim et al. *in review*).

The finalized temporary tattoo sensors will collect physiological information on skin temperature (embedded thermocouple), galvanic skin response, HR (EKG), and environmental UV exposure. Coleman's group has validated skin temperature, skin response, and HR in previous publications (Kim et al. 2011; Harbert et al. 2013; Kang et al. 2015). The data will be transmitted via Bluetooth to a smart phone/tablet. Foneclay, Inc. based in San Diego will aid in optimizing the firmware (software implemented in the Bluetooth chip shown in Fig 3a). Data will be transmitted from the smart phone/tablet on the playgrounds and stored on the UCSD network by transfer VPN connection to a lab server managed by San Diego Supercomputer that Co-I Coleman has maintained for all research studies.

Aim 2 will employ the flexible, low-energy electronics systems developed in Co-I Coleman's Lab to non-invasively and safely collect preliminary physiological data in a small children's population at the Pepper Valley Learning Center in El Cajon, CA. PI Vanos has a developed relationship with the daycare (see Letter of Support). We will first perform preliminary tests on a subset of five students to ensure functionality of the sensors and wireless transmission developed with Foneclay, Inc. Full field tests will then commence, monitoring the thermoregulatory response of 10 children over 45min play periods on five warm-hot summer days in August and September of 2016. The children will also wear UV dosimeters (Figure 2) to quantify their exposure to UV_{Ery} radiation during play (Downs and Parisi 2009; Vanos et al. 2017), for comparison with the flexible tattoo sensors. Ambient monitoring will be accomplished using a high-end weather station continuously collecting air temperature, relative humidity, wind speed, ambient UVB radiation, and incoming and outgoing long and shortwave radiation. A 10W solar panel will power the stations and data transfer. Meteorological equipment will be calibrated, tested, and maintained in PI Vanos' Laboratory for Urban Climate Instrumentation at SIO.

We will monitor children's T_c in the field with new infrared heat sensors are non-invasive, state of the art instruments. The InstaTemp MD™ uses a patented highly sensitive infrared heat sensor placed 2.5cm from the subject's head and is ideal for quick (<5 sec), and is found to be accurate within 5% of T_c compared an indwelling bladder catheter (Gerst et al. 2015). It is a reliable T_c screening method for large groups in ambulatory settings, including children. We will obtain T_c measurements of each subject at 5min intervals, and use these measurements to validate two methods of non-invasive T_c estimation. First, we will test heat balance modeling techniques used by PI Vanos (Eqn. 1 and 2). Second, we will complete a second (exploratory) analysis applying a new Kalman filter (KF) approach devised by Buller et al. (2010). The first approach combines heat balance modeling with T_c estimations from Chan et al. (2001) over time:

$$T_{c_{eq}} = 36.75 + 0.004M + \left(\frac{0.025}{I_{cl}}\right)(T_a - T_{sk}) + 0.8e^{[0.0047(E_{req} - E_{max})]} \quad [1]$$

$$T_{c(t)} = T(0) + T_{c_{eq}} \cdot 0.1^{0.4^{(t-0.5)}} \quad [2]$$

where $T_{c_{eq}}$ is equilibrium T_c, T_a is air temperature (°C), T_{sk} is skin temperature (°C), E_{req} and E_{max} are required and maximum evaporative heat loss, respectively (W m^{-2}), M is metabolic heat load (W m^{-2}), and I_{cl} is clothing insulation (clo). The latter five values are calculated by PI Vanos with human heat balance models (Vanos et al. *in review*; Vanos et al. 2012). Eq. [2] allows for the calculation of T_c at time, *t* (hr), based on the time $T_{c_{eq}}$ begins to undergo a change, T(0). Statistical validation of both techniques allows for the non-invasive identification of the key value to understanding hyperthermia in the ambulatory physiological modeling communities: core temperature. This monitoring will also enable us to ensure that the children are not experiencing high T_c. We will obtain full IRB, parental, and administrative consent before commencing any measurements.

4.1 Statistical Analyses: Aim 2 focuses on the validation of UV measurements and T_c estimations during play in warm-hot weather in a child population. The statistical analysis to validate i) the new sensor UV values, and ii) modeled T_c with measured T_c will involve the use of error statistics, including mean bias and limits of agreement calculated by multiplying the standard deviation of the mean difference between the actual and estimated values of each value values by 1.96 (2 SDs) (Bland & Altman 2010). The overall difference between the two values is expected to lie within these limits of agreement at $p<0.05$ (Atkinson & Nevill 1998). Pearson correlations corrected for repeated measures (Bland & Altman 1995) will provide the relative agreement between actual and estimated values.

4.2 Timeline (Mar 1, 2017–Feb 28, 2018):
Team meetings, organization, preparation: March
Aim 1: Sensor creation, testing, validation: April–July.
Aim 2: IRB: Apr, May; Preparation for field work: May, June; Measurements and validation in playground: Aug, Sept. Data analysis: Oct–Jan; Reporting & begin writing publication: February; Present at IPH Research Day: May 2018.

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Pepper Valley
Learning Center

Jennifer Vanos
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Dear Dr. Vanos,

This is a letter of support for your proposal entitled “Improving the cost-effectiveness of wearable biosensors for environmental health studies” being submitted to the Institute of Public Health at the University of California San Diego (UCSD). We would be happy to have you measure ambient variables and physiological responses in our playground at Pepper Valley Learning Center, and feel that these are important data for the health of our students.

In addition, we can confirm our interest and cooperation to be a part of the data collection on 5–10 students this summer. We have a group of 100 children between the ages of 2 and 12 from the El Cajon, CA area that are ethnically diverse and well-behaved. We feel they will enjoy learning about the weather instrumentation used in your project, and feel empowered by wearing their own sensors to collect personal data. We are excited to be a part of a research study with UCSD and to contribute a community health perspective to your research, outreach, and educational activities.

Thank you for the information you have provided, we look forward to working with you so that you can accomplish your study goals and collect preliminary data to enhance the understanding of children’s heat-health in playgrounds.

Sincerely,

Monica Powell

Monica Powell
Director of Administration, Owner

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SALARY PROJECTION

PI: Jennifer Vanos
Agency: Internal Institute of Public H
Budget Start Date: Mar-01 2017
Budget End Date: Feb-28 2018
ePD#: XXXX
Assist# XXXX
Budget Type Detailed **Years** 1

INSTRUCTIONS: Complete all Yellow Cells
* Input Monthly Salary
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* GSR Scroll down to N142 to complete Tuition/Fee Remission
* Academic : 2% Oct COLA & 5% July Merit
* Staff: 3.5% July COLA
* Postdoc: 5% Annual from start date

Annual Sal escalation rate is: 1.03
NIH Salary Cap: N
Escalate beyond Cap: Y
NIH Salary Cap Eff. 1/11/15: $185,100

DUE DATE: 01/01/2017

Prefix	First Name	Middle	Last Name	Suffix	Academic Staff Graduate Postdoc Undergraduate			% of COL or Merit Increase	Institution Monthly Salary	# Months		Cal Months	Base Salary	% of Effort	Salary Requested	Benefit Rate	Benefits	Yr 1 Sal/Ben Total
Dr.	Jennifer		Vanos			Current Sal..........			6,866.66									0.00%
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						JULY		0.0%	6,866.66		0							82,400
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		Enter Current Payroll Title				Projected Raise after grant start												0
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		Enter Current Payroll Title				Projected Raise after grant start						0.36	Sum. Months					68
	ON CAMPUS/MED C	Enter On or OFF Campus				JULY	2017	0.0%	3,409.00	3	10,227		40,908	12.06%	4,932	1.38%	68	5,000
						OCT	2017	0.0%	3,409.00	5	17,045							
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						Projected Raise before grant start												1.45
						JULY		0.0%	3,409.00		0							40,908
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		Enter Current Payroll Title				Projected Raise after grant start						0.36	Sum. Months					68
	ON CAMPUS/MED C	Enter On or OFF Campus				JULY	2017	0.0%	3,409.00	3	10,227		40,908	12.06%	4,932	1.38%	68	5,000
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						OCT	2017	0.0%	0.00	5	0							
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						Projected Raise before grant start												0.00
						JULY		0.0%	0.00		0							0
		Enter Project Role				OCT		0.0%	0.00	4	0							0
		Enter Current Payroll Title				Projected Raise after grant start												0
	ON CAMPUS/MED C	Enter On or OFF Campus				JULY	2017	0.0%	0.00	3	0	0.00	0	0.00%	-	0.00%	-	-
						OCT	2017	0.0%	0.00	5	0							

Year 01 NGN Costs: $266

NGN costs are listed on the budget page under "Other" with the description of "Communications/Computing Costs".

% of Effort	Salary Requested	Benefit Rate	Yr 1 Sal/Ben Total
0.24	9,864	Total / Subtotal	10,000

Jennifer Vanos

XXXX

DETAILED SUPPLIES AND MATERIALS AND OTHER EXPENSES

Please complete yellow cells. Years 2-7 escalate using the Inflation factor. Fe

Inflation Factor: **1.03**

Years 1

MATERIALS AND SUPPLIES	Year 01
Core Temperature Monitors (x2)	500
Microclimate Variables monitor	3,000
Field Computer	1,500
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
Total Material and Supplies	**5,000**

OTHER EXPENSES	Year 01
Development of125 sensors & Personnel time in clean room	14,734
FoamClay company Wireless Platform setup and support	5,000
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
Total Other Expenses	**19,734**

Jennifer Vanos
RESEARCH & RELATED BUDGET

		Years -----------------	XXXX FUNDS REQU
	A-B. SENIOR/OTHER PERSONNEL	**Year 1**	**Total**
	Salaries	9,864	**9,864**
	Benefits	136	**136**
	Personnel Total	**10,000**	**10,000**
	C. EQUIPMENT DESCRIPTION		
	Equipment Total	**0**	**0**
	Inflation factor for supplies, travel & other:	1.03	
	D. TRAVEL		
	Travel Total	**0**	**0**
	E. PARTICIPANT/TRAINEE SUPPORT COSTS		
	Number of Participants		
1	P/T Tuition	0	**0**
2	P/T Stipends	0	**0**
3	P/T Travel	0	**0**
4	P/T Subsistence	0	**0**
5	P/T Other	0	**0**
	Participant/Trainee Support Total	**0**	**0**
	F. OTHER DIRECT COSTS		
1	Materials And Supplies	5,000	**5,000**
2	Publication Costs	0	**0**
3	Consultant Sevices	0	**0**
4	ADP/Computer Services	0	**0**
5	Subawards/Consortium/Contractual Costs	0	**0**
6	Equipment or Facility Rental/User Fees	0	**0**
7	Alterations & Renovations	0	**0**
8	Communication/ NGN Expenses	266	**266**
9	Tution and Fee Remission	0	**0**
10	Other Project Costs		
	Rental of Space (Excluded from IDC)	0	**0**
	Patient Care Costs (Excluded from IDC)	0	**0**
	Other Expenses	19,734	**19,734**
	Other Project Costs Subtotal	**19,734**	**19,734**
	Other Direct Costs Total	**25,000**	**25,000**
	TOTAL DIRECT COSTS	**35,000**	**35,000**
	Budget Type	***Detailed***	
	Enter modular request $ if applicable:		**0**
	TOTAL INDIRECT COSTS	**0**	**0**
	TOTAL DIRECT & INDIRECT COSTS	**35,000**	**35,000**
	Indirect cost calculation:	**Year 1**	**Total**
	Total subtotal Direct (Face Page)	**35,000**	**35,000**
	Total Direct costs	**35,000**	**35,000**
	Less:		
	Modified Total Direct Costs	**35,000**	**35,000**
			0
	Indirect cost rate	*0.00%*	
	Indirect costs	**0**	**0**
		0	**0**
	TOTAL DIRECT & INDIRECT	**35,000**	**35,000**

Budget Justification

Internal Institute of Public Health Submission: Vanos & Coleman

State Date: March 1, 2017
End Date: Feb 28, 2018

Yearly direct costs estimated for completion of the work and for the primary research team members:

Students:

Vanos:
Graduate Student Support Summer 2017, TBD: $5000, focus on Aim 2 of testing and validating the sensors in field, in addition to statistical analyses.

Coleman:
PhD Student Support: Yun Soung Kim, $5000, focus on Aim 1 of developing and modularization the sensors and the integration of the UV sensor.

[$10,000]

Supplies:

$14,734 in fund are requested for the development of 80 new, modularized flexible sensors with UV sensor integration. This value is based on historical cost estimates of the sensors ($115 each; *$100/sensor plus $15K one-time cost*), which are based on the following: Internal costs for the clean room at the Nano3 fabrication facility at UCSD are $25/hour (see http://nano3.calit2.net/rates/). It takes approximately 3 hours to make a flexible sensor, antenna, and interconnections for integrated circuits contributing $75 per system. The integrated circuits and amplification units for Bluetooth transmission costs approximately $8 per system, and other resistors, capacitors, and wireless oscillators contribute an additional $2 per system. This gives rise to $85/system for upfront development, which will be modularized to reduce future costs and improve scalability. Other un-anticipated costs (e.g. optimization of the fabrication process) comprise an additional $5/system. This totals $90 per system. An additional $10/sensor is required for purchase and integration of Front Edge Technology (http://www.frontedgetechnology.com/) flexible batteries, that are 10×10mm, with 0.15mm thickness, and can be adhered to the flexible adhesives. Data will be transferred via Bluetooth at set intervals to field computers. Additional funding is required for the trial and error nature of the project to develop and test the modularization before field deployment, and to integrate, calibrate, and test the UV-sensitive materials, all of which will require more supplies and time in the clean room.

$500 in funds are requested for two core temperature monitors ($250 each)
$3,000 in funds are requested for the purchase of needed instrumentation/supplies to monitor the microclimate variables of UVB, air temperature, windspeed, relative humidity, and net radiation.
$1,500 is requested for a tablet computer for use in the field to automatically sync with the flexible sensors in real time

[$19,734]

Contract:

$5,000 is requested for Foneclay, Inc. based in San Diego to aid in optimizing the firmware (software implemented in the Bluetooth chip company for setting up wireless platform and support).
[$5,000]

Other:

$266 for Communication/ NGN Expenses

[$266]

Total: $35,000

OMB No. 0925-0001/0002 (Rev. 08/12 Approved Through 8/31/2015)

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Vanos, Jennifer Kristin

eRA COMMONS USER NAME (credential, e.g., agency login): JVANOS

POSITION TITLE: Assistant Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
University of Guelph, Guelph, Ontario, Canada	B.S. (Env)	04/2008	Environmental Sciences
University of Guelph, Guelph, Ontario, Canada	PhD	11/2011	Atmospheric Sciences
Health Canada, Ottawa, Ontario, Canada	Postdoctoral	12/2012	Environmental Health Sciences

A. Personal Statement

My expertise, leadership skills, interdisciplinary background, and motivation within the area of Climate and Health will allow me to successful carry out and lead this proposed research project. I specialize in the study of human biometeorology and bioclimatology, focusing on the impacts of extreme heat, and causes of extreme heat, on human health under dynamic conditions, such as in highly complex urban climates and/or during variable physical activity. My research areas include human heat balance modeling, extreme heat climatology, urban bioclimatic design and instrumentation, children's heat health, and air-effects epidemiology. Many of these research areas focus on understanding the broad impacts of weather and climate variability on specific subpopulations, such as children and athletes. I also utilize *in situ* observations and instrumentation to understand fine-scale human-land-atmosphere couplings in urban microclimates over variable surface types and/or shading configurations. Work that I have completed in this area examines the human physiology connected to weather, including mechanisms of heat formation and dissipation, heat stress on the body, core and skin temperature monitoring, clothing effects, and personal monitoring. Understanding these human heat-balance processes at small scales allow for applications to bioclimatic design, thermal comfort, and mitigation of air pollution and heat stress. This work further improves upon the ability to model the heat balance of humans performing physical activity, and applies findings to health and emergency heat stress preparedness.

Additionally, I am currently successfully administering multiple projects and guiding graduate students (e.g. staffing, research organization and tasks, budgeting), continue collaborate in interdisciplinary research, and produce numerous peer-reviewed publications each year. The proposed research project builds logically on my prior work. Within the context of this project, I will lead and organize the team members, with a specific role in application and testing of the new sensors in real-world conditions to ensure validity and usability. I have experience in these areas from running many of my own field studies with both adults and children during my PhD and as an Assistant Professor. I also bring a dimension of working across disciplines in a transdisciplinary manner within two departments at UCSD (Climate, Atmospheric Science, Physical Oceanography and Family Medicine and Public Health) to bridge the gap between weather, climate, and health.

B. Positions and Honors

Positions and Employment

Jan 2017–	Assistant Professor, Climate, Atmospheric Science, and Physical Oceanography, Scripps Institution of Oceanography; Family Medicine and Public Health, School of Medicine, UC San Diego
8/13–12/16:	Assistant Professor, Atmospheric Sciences, Department of Geosciences, Texas Tech University
2015–2016:	National Wind Institute Affiliated Faculty, Texas Tech University
2013–2016:	Climate Science Center Faculty Associate, Texas Tech University
2013:	Visiting Research Scholar, University of Miami
2011–2012:	Postdoctoral Researcher, Environment Health Sciences, Health Canada

Other Experience and Professional Memberships

2017–	Co-Director, Technology and Health, Institute for Public Health, School of Medicine, UC San Diego
2016–	Steering Committee, Developing an Integrated Heat-Health Information System for Long-term Resilience to Climate and Weather Extremes in the El Paso-Juárez-Las Cruces Region
2015–	Board Member & Planning Chair, *American Meteorological Society,* Board on Environment & Health
2015–	Research Affiliate, Preventing Obesity by Design (POD) Research Group, Texas Tech University
2014–17	Chair, Students and New Professional Group, *International Society of Biometeorology*
2014–	Editorial Advisory Board*, International Journal of Biometeorology*
2014–16	Course Lecturer and Facilitator: Climate Change and Health Research Methods, Umeå Center for Global Research, Umeå University, Sweden. Jun 3–17 2014; Jun 1–14 2015; May 30–Jun 11 2016.
2014–16	Research Associate, 'HEAT' project: A Pufendorf Initiative towards a Multidisciplinary Heat Research Collaboration of humans and ecosystems at Lund University, Sweden
2013–16	Seminar Series Organizer, Climate Science Center, Texas Tech University.
2010	Selected Participant: International Research Institute Climate & Health Course, Columbia University

Professional Memberships

International Society of Environmental Epidemiology; International Society of Biometeorology; International Society of Exposure Sciences; American Association of Geographers (*Climate Specialty Subgroup*); Climate Information for Public Health Network, International Research Institute; Climate and Health Commission; American Meteorological Society; International Association for Urban Climate.

Honors

2014	Ralph E. POWE Junior Faculty Enhancement Awards, Oak Ridge Associated Universities
2014	National Academies Keck *Futures Initiative* Invited Participant
2012	National Science and Engineering Research Council (NSERC) Visiting Fellowship at a Canadian Government Laboratory: Health Canada, Environmental Health Science Research Bureau
2011	Alexander Graham Bell Canada Graduate Scholarship, NSERC, 2011
2011	School of Environmental Sciences, Dean's Graduate Scholarship, University of Guelph, 2011
2011	Summer Institute for Climate and Health, Course Scholarship, *International Research Institute for Climate and Society, CIPHA*. Columbia University, Earth Institute. Palisades, NY, USA. 2011.

Organization/chair/invited talk of symposia and workshops at scientific meetings

2017	Invited Keynote Speaker, Protecting Population Health from Climate Variability and Change, University of Washington Center for Health and the Global Environment, Jan 27, 2017.
2015–	Session Planning Co-chair, Environment & Health Sessions, 2016, 2017, 2018 American Meteorological Society Annual Meetings. *Plan the full 5 days of the Meeting for the Environment and Health Conference, consisting of approximately 16 hosted sessions and 6 joint sessions.*
2016	Invited Keynote Speaker, "*Promotion of Urban Health and Environmental Equity in a Changing Climate,* Conference: "Behind the Perspective – Better Water, More Jobs: Health, Mental Health, and Environmental Equity, Justice, and Sustainability in Underserved Communities", Texas Tech University, Nov 19, 2016.
2016	Workshop Organizer & Steering Committee, *Developing integrated heat-health information for long-term resilience, and early warning, for the El Paso-Juarez, Las Cruces*, July 14–15th, 2016.

2016 International Workshop Organizer & Facilitator, 2nd International SNP Workshop, *"Enhancing the Teaching and Learning of Biometeorology in Higher Education", Old Dominion University, July 28–Aug 1, 2016.*

2015 Invited Speaker, HEAT Project, Pufendorf Institute, Lund University, Sweden, May 19–20, 2015.

2014 Project Co-Lead & Workshop Organizer: 1st International SNP Workshop on Biometeorology and Applied Synoptic Climatology, Umeå Sweden, June 2014.

2013–14 Session Co-Chair, Weather, Climate, and Health, American Association of Geographers, four sessions per year.

C. Contributions to Science

1. Early research throughout my PhD addressed issues related to human biometeorology and human heat balance modeling for thermal comfort in outdoor environments. My research completed in this area comprehensively examined gaps in the scientific literature pertaining to human physiology connected to fine-scale weather features during exercise, including mechanisms of heat formation and dissipation, heat stress on the body, the importance of skin temperature monitoring, the effects of clothing, and applying microclimatic measurements to climate change-related issues. This work further improved upon the ability to model outdoor thermal comfort of humans performing physical activity, and applied findings to health, emergency heat stress preparedness, and urban bioclimatic design—a topic prominent in European city design. Linking these various disciplines provided me with a solid interdisciplinary foundation from which to grow, and further provided a critical foundation for microclimatologists and biometeorologists in the completion and comprehension of climate research involving human physiology. The four publications below built upon one another to jointly demonstrate the viability and potential uses of a specific outdoor human thermal comfort model (COMFA) as a new tool to make heat forecasting more meaningful to the public, emergency responders, and urban planners.

   a. **Vanos, JK.,** Warland, J.S., Gillespie, TJ., Kenny, NA. (2010). Review of the physiology of human thermal comfort while exercising in urban landscapes and implications for bioclimatic design. *International Journal of Biometeorology*. 54(4): 319–334.
   b. **Vanos, JK.,** Warland, JS., Gillespie, TJ., Kenny, NA. (2012). Improved predictive ability of climate-human-behaviour interactions with modifications to the COMFA outdoor energy budget model. *International Journal of Biometeorology*. 56(6), 1065-1074.
   c. **Vanos, JK.,** Warland, JS., Gillespie, TJ., Kenny, NA. (2012). Thermal comfort modelling of body temperature and psychological variations of a human exercising in an outdoor environment. *International Journal of Biometeorology.* 56(1): 21-32.
   d. **Vanos, JK**., Warland, JS., Gillespie, TJ., Slater, GA., Brown, RD., Kenny, NA. (2012). Human Energy Budget Modeling in Urban Parks in Toronto, ON and Applications to Emergency Heat Stress Preparedness. *Journal of Applied Meteorology & Climatology*. 51(9): 1639–1653.

2. Work completed during my Postdoctoral Degree at Health Canada (Environmental Health Science Research Bureau) involved applied synoptic climatology studies assessing the synergistic impacts of synoptic-scale air masses (large-scale weather systems) and air pollution on human health. Air pollution is a significant contributor to illness and death, yet understanding the confounding factors of various pollutants and meteorological variables proves to be difficult, and the effects also vary across different subpopulations. Work that I led in this position addressed air pollution-related mortality in various ages of the population, specifically addressing the elderly, and cause-specific mortality (cardiovascular and respiratory) in the full population across major Canadian cities. Findings demonstrated that mortality risks due to air pollution exposure differ by weather type (hot or cold, dry or moist), with increased accuracy obtained when accounting for interactive effects through adjustment for dependent pollutants using a new distributed lag nonlinear model. We further found that elderly are at a significantly greater risk due to air pollution exposure, yet this is dependent on the pollutant and weather type present. Related research addressed changing air mass frequencies in across Canada and the Midwest United States. Further international research in this area involves weather and health assessments in Korea, Australia, Sweden, and the Russian Far East.

   a. **Vanos, JK**., Cakmak, S. Bristow, C., Brion, V., Tremblay, N., Martin, SL., Sheridan, SC. (2013). Synoptic weather typing applied to air pollution mortality among the elderly in 10 Canadian cities. *Environmental Research*. 126, 66–75.

b. **Vanos, JK.,** Cakmak, S., Kalkstein, LK., Yagouti, A. (2014). Association of weather and air pollution interactions on daily mortality in 12 Canadian cities. *Air Quality, Atmosphere, and Health*. 8 (3), 307–320.
c. **Vanos, JK**., Kalkstein, LS., Sanford, TS. (2014). Detecting Synoptic Warming Trends across the US Midwest and Implications to Human Health and Heat-Related Mortality. *International Journal of Climatology. 35*(1), 85-96.
d. Cakmak, S., Hebbern, C, Cakmak, JD, **Vanos, JK.** (2016). The modifying effect of socioeconomic status on the relationship between traffic, air pollution, and respiratory health in elementary schoolchildren. *Journal of Environmental Management.* 177, 1–8.

3. My most recent area of research is the use of evidence-based research linking environmental design, physiology, and behavior with heat, UVB, and air pollution exposures at a personal scale, particularly in children. This is an important future research avenue, underscoring two research thrusts: 1) the need to for personal assessments of exposures to solve issues at finer scales rather than generalized population outcomes, and 2) children are among the population groups disproportionately affected by ambient extremes and climate change, yet the least studied. Current methods and population-based models lack child-specific inputs and outputs, as well as designated thresholds for accurate predictions of child heat-health impacts, hence I am working towards developing real-world observations using personalized instruments in urban and schoolyard microclimates for risk exposure assessments, and creating adaptive thermal comfort models to understand the perception of heat stress children. Initial findings indicate that more substantive evidence is needed for applicable child-specific policies and guidelines to protect children from the immediate and cumulative consequences of ambient environmental stressors, thus improving health and well-being throughout life. Select new and current projects involve multi-scalar analyses in urban parks and playgrounds, high-spatiotemporal resolution assessments of urban heat islands under various air masses, and new spatially innovative instrumentation methods for physiological, temperature, UVB, and air pollution monitoring using portable and mobile sensors. New research completed in Phoenix also applies remote sensing airborne observations of surface temperatures to *in situ* collection to determine the spatial uncertainty and how it is influenced by the context of measurement. I have also successfully administered thermal perception questionnaires to children throughout 2017 in a two-season field study with 30 different children multiple times per activity session with success. This effort is the first study to publish on children's thermal perception during play in hot weather under different bioclimatic designs in playgrounds, and is in review in *Environmental Health*.

a. **Vanos, JK.** (2015). Children's Health and Vulnerability in Outdoor Microclimates: A Comprehensive Review. *Environment International*. 76, 1–15.
b. **Vanos, JK**, McKercher, GR, Naughton, K. Lochbaum, M. Schoolyard Shade and Sun Exposure: Assessment of Personal Monitoring During Children's Physical Activity. (*2017*). *Photochemistry and Photobiology*, Manuscript ID PHP-2016-10-RA-0251. *In Press.*
c. **Vanos, JK.,** Middel, A., McKercher, GR., Kuras, ER., Ruddell, BL. (2016). A Multiscale Surface Temperature Analysis of Urban Playgrounds in a Hot, Dry City. *Landscape & Urban Planning*. 146, 29–42.
d. Kuras ER, Bernhard MC, Calkins MM, Ebi KL, Hess JJ, Kintziger KW, Jagger MA, Middel A, Scott AA, Spector JT, Uejio CK, **Vanos JK**, Zaitchik BF, Gohlke JM, Hondula DM, 2016. Opportunities and Challenges for Personal Heat Exposure Research. *Environmental Health Perspectives.* Accepted Nov 2, 2016.

Complete List of Published Work

D. Research Support

Ongoing Research Support

Texas Tech Transdisciplinary Research Academy, 2016–2017 (**Lead-PI**). *"The Value of Greening Urban Environments."* Co-Investigator: David Driskill (Texas Tech University).

Tromp Foundation (**Lead-PI**) *"Enhancing the Teaching and Learning of Biometeorology in Higher Education"* Co-Investigators: Cameron Lee (Kent State University), Jeremy Spencer (University of Akron), Rebekah Lucas (University of Birmingham), David Hondula (Arizona State Univ), Michael Allen (Old Dominion).

National Science Foundation, 2015–19, **Senior Personnel**, Sustainability Research Networks. *"The Urban Water Innovation Network (U-WIN): Transitioning Toward Sustainable Urban Water Systems"* Principal and Co-Investigators: Mazdak Arabi (Colorado State University), Matei Georgescu (Arizona State University).

Completed Research Support

National Wind Institute, 2015 ($39,714, **Co-PI**) *"Establishment of a Joint Atmospheric Sciences-National Wind Institute Research Electronics Lab at Texas Tech University."* Principal Investigator: Eric Bruning (Texas Tech University). ***Refurbished a storage space to become a new space for atmospheric science instrumentation projects.***

National Institutes of Health (**Co-PI**). National Institute on Minority Health and Health Disparities. "*Linking climate, air pollution, and housing conditions to develop strategies to reduce racial disparities in infant mortality"*. Co-Is: Robert Levine (Baylor Medical College), Barbara Kilbourne (Meharry), Lisa Gittner (TTU). 2015–16.

Tromp Foundation Grant. *"Extending the application of climate and health research tools into distinct climate regimes in Russia, India, and New Zealand."* International Society of Biometeorology (**Co-Lead PI** with Dr. David Hondula, Dr. Simon Gosling). 2013–2014.

TTU Transdisciplinary Research Academy, 2014–2015**, Co-PI**. *"A Data-Intensive GIS Approach for Spatial Environmental Epidemiology*." **Co-Investigators**: Dr. Guofang Cao, Dr. Yong Chen.

*__Oak Ridge Associated Universities__, 2014–2016 ($10,000, **Lead-PI**). "*Real-time intra-urban air quality monitoring through the use of mobile platforms.*" Ralph E. POWE Junior Faculty Enhancement Award. ***Lead research on air pollution sensors used to measure and quantify exposures to urban pollutants.***

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Todd P Coleman

eRA COMMONS USER NAME (credential, e.g., agency login): TODD_COLEMAN

POSITION TITLE: Associate Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
University of Michigan, Ann Arbor MI	B.S.	2000	Electrical Engineering
University of Michigan, Ann Arbor MI	B.S.	2000	Computer Engineering
MIT, Cambridge, MA	Ph.D.	2006	Electrical Engineering
MIT, Cambridge, MA and MGH, Boston, MA	Postdoctoral	2005-2006	Neuroscience

A. Personal statement

My research bridges seemingly disparate fields – applied mathematics, neuroscience, and bio-electronics – to (a) understand intra-organ and inter-organ function (e.g. brain, heart, lungs) in terms of a complex interacting stochastic network and (b) developing novel ways to quantify and/or combat illness.
My research expertise in applied probability has enabled me to develop scalable biological signal processing algorithms that elucidate the statistical dynamics underlying biological processes. More recent efforts involve the development of body-integrated “epidermal electronics” systems - which appeared in *Science* and have been featured on CNN, the *New York Times*, and *BBC* – to perform physiological monitoring unobtrusively and wirelessly.

I also consistently build upon my group’s new methods to developing scalable, low-complexity algorithms that perform Bayesian inference with superior performance/complexity tradeoffs as compared to existing techniques. These methods, that use physiologically guided statistical models, are applied to relate multiple physiological modalities to one another to help statistically characterize the physiology of the central and peripheral nervous system.

By leading the NSF IGERT grant “Neuroengineering: A Unified Educational Program for Systems Engineering and Neuroscience”, at U. Illinois, I built a highly collaborative, transdisciplinary program to develop imaging, audition, and brain-machine interface clinical applications. Now at UCSD Bioengineering, I train students on the use of applied probability and bio-electronics to solve important problems at the intersection of engineering and medicine.

Within the context of this project, I plan to refine the flexible electronics technology in a modularized fashion for recording ECG, temperature, and galvanic skin response and develop appropriate statistical signal processing methods to further elucidate the role that heat and environmental exposures play in affecting the physiology of children on playgrounds.

B. Positions and Honors

Positions and Employment

2006-2011 Assistant Professor, Department of Electrical and Computer Engineering and Neuroscience Program, University of Illinois, Urbana-Champaign, Ill
2011- Associate Professor, Department of Bioengineering, University of California, San Diego (UCSD)
2013- co-Director, Center for Perinatal Health, Institute of Engineering and Medicine, UCSD
2015- Adjunct Associate Professor, Department of Ophthalmology, School of Medicine, UCSD

Other Experience and Professional Memberships

2006 – Senior Member, IEEE
2006- Member, Society for Neuroscience
2012- Associate Editor, *IEEE Transactions on Biomedical Engineering*

Honors

1999 Rhodes Scholarship Semi-Finalist
1999 University of Michigan College of Engineering Senior Class Prize
2000-2004 National Science Foundation Graduate Research Fellowship
2002 MIT Morris J. Levin Award for Best Oral Thesis Presentation
2010-2011 Fellow, Center for Advanced Study, University of Illinois
2014 Featured in *Cell*'s 40th anniversary "40 under 40" celebration
2015 Gilbreth Lecturer, National Academy of Engineering
2015 Selected in the "Root 100", *one of 100 African Americans, ages 25 to 45, responsible for the year's most significant moments, movements and ideas*
2015 Invited speaker, TEDMED
2016 UCSD Campus-wide Diversity Award Recipient
For individuals, departments, organizational units and students who have made outstanding contributions in support of UC San Diego's commitment to diversity

Synergistic Activities

2009-2012 DARPA ISAT study group
Selected as 1 of 30 scientists/engineers in the US. ISAT main objective: assess the state of advanced information science and technology related to the U.S. Department of Defense. The group identifies new or improved technologies, recommends research directions, and performs three large studies each year, which are kept confidential to the public.
2010-2020 Assistant Dir. for Diversity, NSF Science & Technology Center on "Emerging Frontiers of the Science of Information"
2015-2020 Associate Dir. for Education, NSF Nanotechnology Coordinated Infrastructure (NNCI) at UCSD
2016- Volunteer, IEEE Technical Advisory Board Ad-Hoc Committee on Women and URMs
2016- Independent Expert Committee Member, NIH Pediatric Research Using Integrated Sensor Monitoring Systems (PRISMS)

Organization/chair of symposia and workshops at scientific meetings

Aug 2013 Organizing Committee Member, NSF Workshop on Grand Challenges in Mapping the Human Brain
Nov 2014 Steering Committee Member, National Academies Keck Futures Initiative (NAKFI) Symposium on Social Behaviors
2018 Program Co-Chair, 40th Annual International Conference of the IEEE Engineering and Medicine Biology Society

Grant Reviewer

2010 – NSF, Directorate for Computer & Information Science & Engineering (CISE)
2016 - NIH: Ad hoc member, Neuroscience and Ophthalmic Imaging Technologies (NOIT) Study Section

Ad Hoc Reviewer for the Following Journals:

Journal of Neuroscience, Journal of Neurophysiology, Neural Computation, Proceedings of the National Academy of Sciences, Journal of Computational Neuroscience, NeuroImage, PLoS One

C. Contributions to Science

1. My early publications involved developing quantitative ways to understand the spatio-temporal dynamics of biological processes, with an emphasis on neuroscience. With the increasing ability to record multiple neural signals at different brain areas simultaneously, one core issue in neuroscience research is understanding the mechanistic phenomena and how to analyze these ensemble recordings and infer the structure of these mechanisms. One such approach to attempt to understand this mechanistic phenomena is by using statistical approaches that quantify how the past of processes affect the future of others, e.g. a measure of not just correlation: but causation. We have built upon Nobel laureate Clive Granger's methods to infer causality, which was limited to linear Gaussian models. We have shown that the directed information is a generalization of Granger's mathematics, which is totally consistent with his viewpoint underlying his quantitative approach. We have developed provably good estimation algorithms to estimate these quantities from data and have demonstrated how the network causal dynamics represent information processing in biological systems (e.g. the brain). Most recently, we have developed extremely efficient Bayesian inference algorithms that can be implemented in cloud infrastructures, facilitating real-time data analysis.

    A. **T. P. Coleman** and S. Sarma, "A Computationally Efficient Method for Nonparametric Modeling of Neural Spiking Activity with Point Processes ", *Neural Computation*, Volume 22, Issue 8, August 2010.
    B. S. Kim, C. Quinn, N. Kiyavash, and **T. P. Coleman**, "Dynamic and Succinct Statistical Analysis of Neuroscience Data", invited paper, *Proceedings of the IEEE*, April 2014.
    C. K. Takahashi, S. Kim, **T. P. Coleman**, K. A. Brown, A. Suminski, M. Best, and N. G. Hatsopoulos, "Large-scale spatiotemporal spike patterning consistent with wave propagation in motor cortex," *Nature Communications*, May 2015.
    D. C. Quinn, N. Kiyavash, and **T. P. Coleman**, "Directed Information Graphs", *IEEE Transactions on Information Theory*, December 2015.

2. My subsequent publications involved the design of brain-computer interfaces from the perspective of feedback engineering and team decision theory. A brain-machine interface is a system comprising a direct communication pathway between the brain and an external device. Our research group has developed an interpretation of the BMI as a system comprising multiple agents cooperating to achieve a common goal. This "team decision theory" viewpoint has led us to leverage insights from feedback information theory and control theory to develop direct brain control systems that are easy to use, are theoretically optimal, and attain previously un-attainable performance, including the neural control of a remote unmanned aerial vehicle.

    A. Omar, A. Akce, M. Johnson, T. Bretl, R. Ma, E. Maclin, M. McCormick, and **T. P. Coleman**, "A Feedback Information-Theoretic Approach to the Design of Brain-Computer Interfaces", *International Journal on Human-Computer Interaction*, January 2011.
    B. R. Ma, N. Aghasadeghi, J. A. Jarzebowski, T. W. Bretl, and **T. P. Coleman**, "A Stochastic Control Approach to Optimally Designing Variable-Sized Menus in P300 Neural Communication Prostheses", *IEEE Trans on Neural Systems and Rehabilitation Engineering (TNSRE)*, January 2012.
    C. Kulkarni and **T. P. Coleman**, "An Optimizer's Approach to Stochastic Control Problems with Nonclassical Information Structures", *IEEE Transactions on Automatic Control*, April 2015.
    D. J. Tantiongloc, D. A. Mesa, R. Ma, S. Kim, C. A. Gil, J. C. Rosa, V. Manian, and **T. P. Coleman**, "An Information and Control Framework for the Design of Human-Computer Interfaces", *Proceedings of the IEEE*, in press

3. Capabilities for non-invasive measurement of physiologic signals are important because they support many critical biomedical applications. Currently, recording physiologic signals in mobile environments is a challenge because conventional measurement devices have rigid or mildly flexible construction and bulky cables for signal conduction. Our research group has developed foldable, stretchable electrode

arrays that can non-invasively measure physiological signals and wirelessly transmit them. The electrodes rely on layouts recently developed for silicon electronics that offer linear elastic responses to applied force, with the capacity to fold, twist and deform into various curved shapes. Stretchable electronics have the key advantage that they can wrap arbitrary, curvilinear surfaces and, at the same time, achieve mechanical properties that approach those of tissues of the human body (e.g. skin). Our technology has been successfully piloted in a variety of clinical settings, including neonatal seizure monitoring (EEG), pregnancy monitoring (EEG), sleep monitoring in the ICU, and cognitive monitoring.

A. D. Kim, N. Lu, R. Ma* Y. Kim, R. Kim, S. Wang, J. Wu, S. M. Won, H. Tao, A. Islam, K. J. Yu, T. Kim, R. Chowdhury, M. Ying, L. Xu, M. Li, H. Chung, H. Keum, M. McCormick, P. Liu, Y. Zhang, F. G. Omenetto, Y. Huang, **T. P. Coleman**, J. A. Rogers, “Epidermal Electronics”, *Science*, August 12, 2011
B. Harbert MJ, Rosenberg SS, Mesa D, Sinha M, Karanjia NP, **Coleman TP**, “Demonstration of the Use of Epidermal Electronics in Neurological Monitoring”, *Annals of Neurology*, Oct 2013
C. J. A. Fan, W. Yeo, Y. Su, Y. Hattori, W. Lee, S. Jung, Y. Zhang, Z. Liu, H. Cheng, L. Falgout, M. Bajema, **T. Coleman**, D. Gregoire, R. J. Larsen, Y. Huang, and J. A. Rogers, “Fractal design concepts for stretchable electronics”, *Nature Communications*, February 2014
D. D. Kang, Y. S. Kim, G. Ornelas, M. Sinha, K. Naidu, and **T. P. Coleman**, “Scalable Microfabrication Procedures for Adhesive-Integrated Flexible Electronic Sensors”, *Sensors*, September 2015.

Full Publication List Available At: https://scholar.google.com/citations?user=PYZokVsAAAAJ&hl=en

D. Research Support
Ongoing Research Support

CCF-0939370 (Szpankowski, W.) 6/10-6/20
NSF Science Technology Center
“STC: Emerging Frontiers of the Science of Information”
Goals: The goal of this Science & Technology Center is to advance science and technology through a new quantitative understanding of the representation, communication, and processing of information in biological, physical, social, and engineered systems. In view of this, the Center focuses its research around three application thrusts: Life Sciences, Communication, and Knowledge Extraction from massive datasets.

Hartwell (Harbert, M.) 04/14 – 03/17
The Hartwell Foundation
“Brain Activity During Birth for Prediction of Newborns at Risk for Brain Injury”
Goals: Our primary aim is to monitor the neurophysiology when the fetus becomes a newborn by taking its first breath. Very recent evidence suggests that abnormal electrical brain activity during the first minutes of the birth transition may be predictive of asphyxia. However, conventional technology for measuring brain activity consists of bulky wired electrodes and instrumentation that requires special expertise and a lengthy set-up time. To address the need for early recognition of abnormal electrical brain activity in newborns, we propose to optimize a wireless approach based upon utilization of a thin flexible electronics that can be conveniently and quickly applied to the skin.

1R01EB019337 (co-PIs: Coleman, T.; Fatone, S.; Rogers, J.; Huang, Y) 10/14-5/18
NIH/NIBIB
“SCH: Interface Monitoring System to Promote Residual Limb Health”
Goals: This proposal aims to develop a stretchable and flexible sensor technology capable of transforming healthcare from reactive and hospital-centered to preventive, proactive, evidence-based, and person-centered. The resulting ‘epidermal’ electronic devices will allow clinicians to monitor their patients, and the general public to assess, continuously, their health and well-being. The proposed work will focus on the development of an interface monitoring system designed to promote residual limb health in persons who wear prostheses.

ARO-MURI (Kiyavash, N.) 7/15-7/20

"Adaptive Exploitation of Noncommutative Multimodal Information Structure"
Goals: The project will make advancements related to the non-commutative information structures that are intrinsic to hierarchical representations, distributed sensing, and adaptive online processing. In non-commutative information structures, the knowledge extracted from the data is dependent on the order of operations and direction of information flow. Non-commutativity is intrinsic to emerging complex sensing and processing systems. The performance of such systems depends on the ordering or partial ordering of the sequence of information sharing actions taken across the network. With adaptive exploitation, this project will develop efficient approaches to fine-tune decision-making as new information arrives.

IIS- 1522125 (co-PIs: Coleman, T., Cosman, P., Dey, S., Nguyen, T.) 9/15-8/19
NSF/IIS
"SCH: INT: Collaborative Research: Replicating Clinic Physical Therapy at Home: Touch, Depth, and Epidermal Electronics in an Interactive Avatar System"
Goals: This project uses bio-electronics, computer vision, computer gaming, high-dimensional machine learning, and human factors to develop a home physical therapy assistance system. During home exercises, patient kinematics and physiology are monitored with a Kinect color/depth camera and wireless epidermal electronics transferable to the skin with a temporary tattoo. The project involves optimization of electrode design and wireless signaling for epidermal electronics to monitor spatiotemporal aspects of muscle recruitment, hand and body pose estimation and tracking algorithms that are robust to rapid motion and occlusions, and development of machine learning and avatar rendering algorithms for multi-modal sensor fusion and expert-trained optimal control guidance logic, for both cloud and local usage.

ECCS- 1542148 (Lu, Y.) 9/15-8/20
NSF/ECCS
"NNCI: San Diego Nanotechnology Infrastructure (SDNI)"
Goals: The San Diego Nanotechnology Infrastructure (SDNI) site of the NNCI at the University of California at San Diego offers access to a broad spectrum of nanofabrication and characterization instrumentation and expertise that enable and accelerate cutting edge scientific research, proof-of-concept demonstration, device and system prototyping, product development, and technology translation. The SDNI site will build upon the existing Nano3 user facility and leverage additional specialized resources and expertise at the University of California at San Diego. The SDNI site will offer state-of-the-art knowhow, tools, and services of nanotechnologies to all interested users across the nation in a user friendly, timely, and cost effective manner.

Completed Research Support

GF-554-3288 (Harbert, M.) 12/12 – 12/15
The Gerber Foundation
"Temporary Tattoo Electronics for Unobtrusive Detection of Newborn Seizures"
Goals: Our primary aim is to evaluate the ability of the wireless epidermal electronic system to detect newborn seizures compared to conventional electroencephalography. This could revolutionize monitoring the electrical activity of the newborn brain, speeding delivery of care and increasing patient comfort significantly.

SMA-1451221 (Chiba, A.) 9/14-8/16
NSF/SMA
"Socially Situated Neuroscience: Creating a Suite of Tools for Studying Sociality and Interoception"
Goals: The social world exerts a powerful influence on our behavior and our brains. Yet, much of our knowledge regarding the function of neurons in the brain is based on neural recordings from animals or humans who are isolated from their social counterparts. Thus, there exists a knowledge gap that is largely due to the lack of recording and behavioral tools for doing experiments in the social realm that still allow proper experimental control. The aim of the project is to fill this gap by developing the following: 1) light, wireless, flexible recording sensors that can provide brain and body signals in a non-intrusive manner; 2) a robot with a synthetic, biologically inspired brain that can act as a socially relevant entity; and 3) a set of novel experiments to interrogate the function of brain circuits and their relationship to other biological signals during social interactions and decisions.