Nanofiber Thermoregulation and Dexterity

Project Description

Personal Protective Equipment (PPE) exist for all types of employment and play a critical role in allowing people to perform tasks in extreme environments. PPE need to provide both adequate thermoregulation and physical protection from potential sources of injury. Mittens and gloves specifically play an important role in protecting the hands and preserving the ability to interact with great dexterity because the hands are the coldest area of the body.[1,2] The key challenge, then, is to balance comfortable skin temperature with the ability to move the hand and phalanges for gross and fine motor movement.

An easy solution to preventing unsafe increases and decreases in skin temperature is to increase the thickness of the material, but this may lead to perceptual or physical decrements in movement and fine motor skill.[3,4] Therefore, purely increasing material thickness is not an adequate solution because many tasks would be significantly more challenging due to a lack of range of motion. In addition, short exposure to cold water quickly cools the hands and fingers, further reducing tactile feedback.[5,6] Furthermore, the type of glove, material, amount of layers, and thickness have all been shown to influence grip strength, drawing tasks, and other manual dexterity tasks.[2,3,7] Differences in the thickness of commercial gloves also impact grip strength and discomfort when the hand is exposed to cold temperatures near 5°C. Thermoregulation is a priority, but dexterity is also necessary, and more thought should be given in regard to how human movement is impacted by the type and thickness of the material.

The continued effort to make equipment better at protecting people has led to the development of nanofiber materials. Nanofibrous materials are ultra-thin fibers, with low thermal conductivity, that have a wide range of applications including wound dressings, textiles, protective equipment, and many more.[8,9] The electrospun materials consist of interwoven continuous polymeric nanofibers with a typical length of tens of centimeters or more.[10] Polyurethane nanofibrous materials similar to those proposed for testing have been safely used as vapor permeable membranes in protective clothing fabrics.[11,12] The nanofiber's ability to act as a protective heat barrier when formed into layers as small as a micrometer is especially useful when trying to balance thermoregulation and dexterity. These unique qualities may be especially useful for the National Aeronautics and Space Administration during spaceflight and other suborbital missions, firefighters experiencing extremely hot temperatures, divers experiencing extremely cold temperatures, or the layman who may experience less extreme, but still uncomfortable, thermal sources. This project works to test an electrospun nanofibrous mitten exposed to extreme temperatures that may be applied to a multitude of use cases. Our **Overall Hypothesis** is that the nanofiber mitten will be superior to the mitten made from a more common and commercially available material.

Methodology

Recruitment: The proposed study is novel, such that, we were unable to use effect sizes from the literature to determine our sample size. Instead, we found review articles that summarize related literature. One of those papers, Ray et al., was used to extract 20 studies showing the basic effects and modulating factors of cold exposure on manual performance.[13] A median value of 16 participants was taken from 20 studies with a range of 6 to 620 participants. From our second review by Dianat et al. (2012), 7 papers were sampled from 21 studies on the effect of gloves on manual dexterity as assessed by a pegboard test.[14] Of those papers, the median number of participants per study was 20 with a range of 10-50. To account for the possibility of incomplete data due to equipment failure or participant attrition, based on Dianats median number of participants (n = 20), 10 additional participants will be recruited for a total of 30 participants. Because we are most interested in thermoregulation and dexterity without confounding factors that may prevent homeostatic temperatures or motor control (i.e., age, disease, disability) we will only recruit young adults between the ages of 19-35 within the local Omaha community.

Preliminary Work: A great deal of effort has been put into creating neoprene and nanofiber mittens and the investigation of their ability to resist extremely hot and cold temperatures (Figure 1). Critically, **nanofiber** produced **lower terminal temperatures** in the **hot condition** (Figure 1 bottom left): 58.0°C (Nanofiber Contact), 58.6°C (Neoprene Contact), 43.8°C (Nanofiber Ambient), 51.1°C (Neoprene Ambient). In addition, **nanofiber** produced **higher terminal temperatures** in the **cold condition** (Figure 1 bottom right): -10.7°C (Nanofiber Contact), -27.3°C (Neoprene Contact), 0.6°C (Nanofiber Ambient), -9.8°C (Neoprene Ambient). Our preliminary work follows our assumptions about the ability for the nanofiber material to resist changes in temperature and we expect the conclusion of this project to be successful.

General Experimental Protocol: Prior to their arrival, participants will be asked to abstain from caffeine intake 4 hours, food 4 hours, alcohol 24 hours, and heavy exercise 24 hours prior to their scheduled data collection in an effort to maintain metabolic changes occurring from these confounders. Participants will also be asked to wear apparel that involves close toed shoes, covers the legs, and apparel similar to a short sleeve/t-shirt. Upon their arrival, all participants will be required to wear a flame resistant lab coat during the temperature tests that covers their arms but not during the dexterity tests. Anthropometric measurements of the hand will then be recorded including hand length (perpendicular distance from a line drawn between the styloid processes to the tip of the middle finger) and width (projected distance between radial and ulnar metacarpals at the level of the metacarpal heads from the second to the fifth metacarpal), and the length of the middle phalanges. The entire session is not expected to exceed 2 hours in length. All participants will complete the dexterity tests and then the thermoregulation tests.

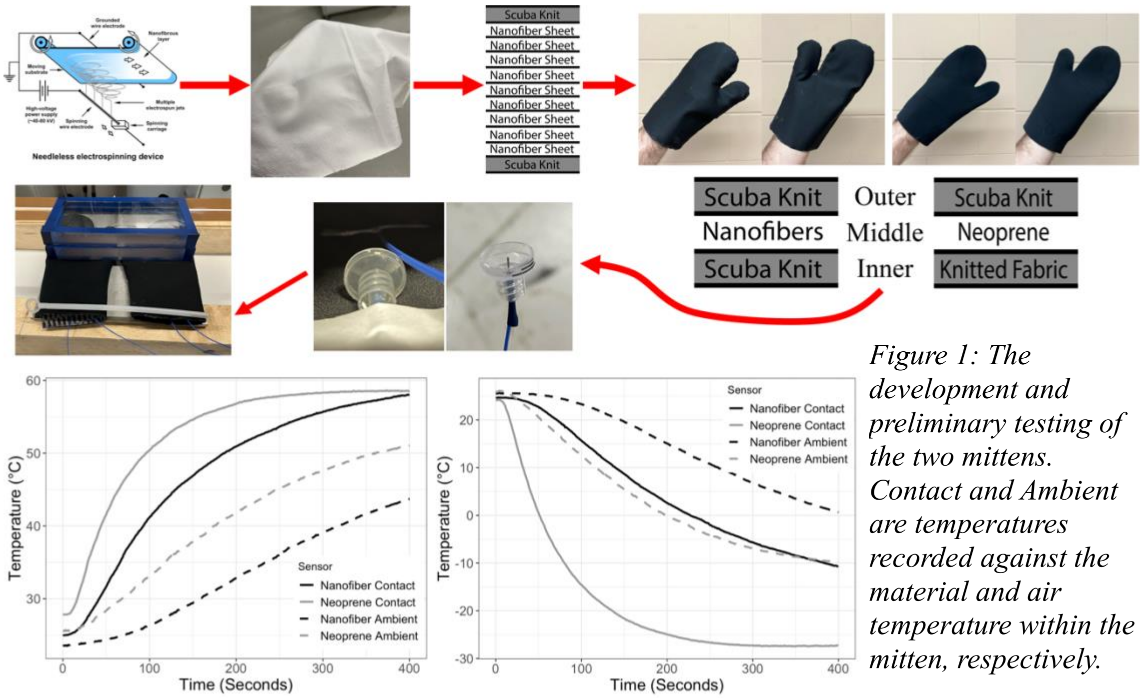

Figure 1: The development and preliminary testing of the two mittens. Contact and Ambient are temperatures recorded against the material and air temperature within the mitten, respectively.

Experiment Specific Protocol: For the **Dexterity Test**, participants will don the mitten in their right hand and be given approximately one minute to familiarize themselves with the mitten during their first exposure to the material. In a seated position, with their feet on the ground, the participant will then be given a single attempt at the box and block and Pegboard Tests. For the box and block test, participants will be instructed that their goal is to move as many blocks over the partition as possible, one at a time, within one minute into the adjacent box. The researcher will demonstrate the task while providing verbal instruction, and then the participant will be given a 15 second test trial for familiarization of the task. Finally, the participant will then complete their tested 1 minute trial. In the Purdue Pegboard Test, participants will complete a modified Purdue Pegboard Test that only requires the "right hand" trial to be completed. This trial includes placing pins into small holes in a required order. Following verbal instruction, participants will be given the opportunity to briefly practice the task. They will then be given 30 seconds to complete the "right hand" task. Following the conclusion of both dexterity tests, participants will also be asked perceptual questions on their opinion and preference between the mittens. In the **Thermoregulation Test**, the same mittens will be used from the Dexterity Test. To measure skin temperature, each participant will be equipped with four Bead Probe Thermocouples (Phidgets, Inc., Calgary, Canada). On each hand, two sensors will be taped on the palmar surface of the third distal phalange, and near the proximal segment of the first metacarpal. Prior to the hot and cold tests, the participant will don each mitten and be asked to keep their hands at rest, at the same horizontal level, and to avoid touching any surface for 10 minutes while their skin temperature is being recorded. Participants will then complete a hot temperature condition (~65°C) or a cold temperature condition (~ -80°C) using metal plates heated and chilled to the desired temperatures. In a seated position, with their feet on the ground, the participant will place both gloved hands on the metal plate for 5 minutes while skin temperature is recorded. A brief rest period will occur (~5 minutes) where the participants will take off the mittens to allow the materials to reach normal room temperatures (~20°C). This rest period, in addition to completing another baseline test prior to the final 5 minute hot/cold trial, is sufficient for thermal sensations and temperatures to normalize.[15,16] We have also developed a simple piece of software that allows for real-time viewing of skin temperatures that may approach unsafe levels. Our preliminary work and pilot testing suggests dangerous temperatures will never occur. Participants will also be asked to make ratings of the temperature and comfort of both hands as well as mitten preference after both trials have concluded.

Hypothesis 1: The flexibility and thickness of the two materials slightly differ and we predict the nanofiber mitten will permit better performances in both dexterity tasks compared to the neoprene mitten.
Hypothesis 2: At the conclusion of both dexterity and thermoregulation tests, we expect the perceptual rating of the nanofiber material to be equal to, or better than the neoprene mitten.
Hypothesis 3: The thermal conductivity between the two materials are not the same and we hypothesize that the temperature rate of change will be slower for the nanofiber mitten compared to the neoprene mitten.

Hypothesis 4: The heat capacity between the two materials are not the same and we hypothesize that the nanofiber mitten will have less extreme temperatures at the conclusion of each thermoregulation test compared to the neoprene mitten.

Planned Statistical Analysis: Points are given for the completion of each dexterity task, for example, one point is awarded for each block transferred in the Box and Block Test. A Bayesian paired t-test will be conducted to assess differences in score between the two mittens following the completion of the Box and Block Test. For the Purdue Pegboard Test, a separate Bayesian paired t-test will be conducted to assess differences in score between the two mittens. The higher the score for each test, the better the performance of the individual. For the thermoregulation tests, two sensors will be placed on the palmar surface of the third carpal and distal phalange, and on the dorsal surface of the third carpal and proximal phalange of each hand. I will perform a Bayesian three-factor, $2\ (Mitten) \times 2\ (Sensor\ Location) \times 2\ (Time)$, repeated measures analysis of variance to investigate the combined influence of mitten material, sensor location, and time. Our dependent variable is the change in skin temperature. Additionally, a Bayesian multilevel model will also be deployed to investigate the effect of time on skin temperature when considering variations in sensor placement, material, and individual variations between participants. Furthermore, other tests including a two-way analysis of variance and necessary post hoc tests may be required depending on the results of this study.

Conceptual Importance: Thermal insulation is crucial to survive in extreme environments where the human body cannot maintain a safe and comfortable temperature without protective clothing. Some modern materials for personal protection have many disadvantages, including high weight, low flexibility, and poor insulation that deteriorates over time. There is a critical need to create lightweight, durable, and flexible material with ultra-high thermal insulation properties that will provide complete protection to the wearer without restricting motor dexterity. A promising design, nanofiber mittens, have been developed in the Biomechanics Research Building that are a potential replacement for standardized equipment in many occupations operating within extremely hot or cold environments. The testing of these new mittens will directly impact the apparel industry and can be used for thermal insulation of the human body.

Contribution to Student's Graduate Studies: This project will provide me with the opportunity to continue my own line of research that has followed me since the beginning of my undergraduate career. This project is an extension of my undergraduate research papers and master's thesis, and has provided me with the unique opportunity to gain experience conducting a follow-up study to my previous work. In this project, I will gain important experience for **recruitment**, **data collection, statistical analysis**, as well as **conference and manuscript preparation and presentation**. My time already committed to this project has been invaluable to my development as an early career researcher developing an independent line of research. Funding acquisition will also make my transition from doctoral to post-doctoral work easier.

Project Timeline

Year	**2025**			
Month	**Feb**	**Mar**	**Apr**	**May**
Recruitment	■	■	■	
Data Collection	■	■	■	
Data Analysis	■	■	■	■
Manuscript Preparation			■	■
RCAF		■		

Previous Funding Received: GRACA has partially funded my dissertation, *The Influence of Gait Variability on Human Odometry*, which is a project answering a completely separate research question (presenting at RCAF 2025). In that project, participants walk predefined distances while blindfolded to monitor their perception of distance. The nanofiber project, proposed in this document, is a different line of research focused on physiology rather than biomechanics in my dissertation.

Role of Student and Faculty Mentor: The student will be responsible for 1) continuously affirming the IRB is being followed appropriately, 2) **recruitment** and scheduling, 3) **experimental protocol, data collections and analysis**, 4) **preparing and submitting manuscripts** to peer-reviewed journals, and 5) **presenting the research study at the UNO Research and Creative Activity Fair** and in at least one national conference (i.e., American Society of Biomechanics). The role of the faculty mentor will be to 1) guide and supervise the research, 2) oversee weekly meetings and reading clubs to ensure success, and 3) provide feedback on IRB, manuscripts, and conference abstracts.

Budget Justification

Item	Price
Participant Stipend	$600 (30 participants at $20 for volunteering)
Student Stipend	$4,400.00 (200 hours at $22/hour)
Total	**$5,000.00**

Participant Stipend

For volunteering their time, we would like to give each participant $20 for their contribution to this project. We will be recruiting 30 participants, resulting in a total Participant Stipend of $600 ($30\ participants * \$20.00 = \$600.00$). The participant stipend will be provided to the participants upon completion of the experimental protocol and will assist in expediting the recruitment processes.

Student Stipend

I am currently a fourth year doctoral assistant in the Biomechanics Research Building. It is expected that 10 hours will be spent preparing for data collections (participant recruitment, scheduling, etc.) that will take approximately 2 hours per participant. Data processing will then take approximately one hour per participant. Following data processing, approximately 100 additional hours will be spent in data analysis, interpretation, and writing the results into manuscripts and abstracts that will be presented at the UNO Research and Creative Activity Fair and other international or national US conferences. At least 200 hours are expected to be attributed to this project. The **Student Stipend** will provide important financial security, allow peace of mind, and support additional time to collect and analyze data for the research project's success.

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DEPARTMENT OF BIOMECHANICS
Center for Research in Human Movement Variability

September 16, 2024

Dear Review Committee,

In this letter, I am pleased to express my wholehearted endorsement of Mr. Tyler Wiles' application for the GRACA award, entitled 'Nanofiber Thermoregulation and Dexterity'. Throughout the planning of this project, Tyler has displayed a remarkable ability to identify and address significant gaps in existing literature that underpin this study.

As Tyler's mentor and chief sponsor, I (Dr. Likens) am committed to ensuring he has access to the best resources, guidance, and tools to facilitate a fruitful dissertation. I will be closely involved in supervising every facet of this project, as well as Tyler's progression in both academic and laboratory settings. Tyler's academic history uniquely qualifies him for this research. He earned a BS Degree in Kinesiology with a Health Science focus in May 2019 and a MS in Kinesiology in May 2021 from California State University San Marcos. Having completed the bulk of his coursework at UNO, he recently advanced to PhD candidacy. His experiences have significantly influenced the shaping of this project, drawing from courses in biomechanics, research methodologies, physiology, and statistics.

Furthermore, Tyler's accomplishments include the publication of two peer-reviewed articles during his undergraduate years and his master's thesis publication. During his PhD, he has published four papers, with others under review. One of his papers was published in the esteemed *Nature Scientific Data*. He has also published in Computational and Structural Biotechnology Journal, another high impact outlet, His frequent participation in conferences exemplifies his smooth transition from graduate to doctoral studies, highlighting his adeptness at conveying his research. The scholarships and grants he has procured, including a $17,352 award from his former institution, a $6,000 grant from the NASA Nebraska Space Grant, a $5,000 GRACA for his dissertation, and co-authoring a successful $150,000 University of Nebraska Collaboration Initiative proposal, underline his ability to fund his research. Tyler's drive is rooted in his inquisitiveness and his ambition to enhance his set of skills, positioning him favorably for future postdoctoral and faculty roles. Since he joined our team, Tyler has consistently displayed leadership and mentorship towards junior students. His zest for knowledge is evident in our team and seminar meetings, where he readily delves into topics beyond his immediate expertise.

Should Tyler's proposal receive funding, I will work closely with him on data collection, results interpretation, and ensuring IRB compliance. I will also critique and offer insights on his dissemination efforts. Our routine consultations will be avenues for Tyler to garner feedback and tackle any research-related challenges, while also discussing other pivotal matters like publication and long-term career goals.

To conclude, Tyler is exceptionally equipped to shoulder the tasks associated with this guided research project. His academic background, experiences, and inherent attributes prime him for success in this venture and others to come. It's a privilege to mentor Tyler in this journey.

Sincerely,

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