# Background and Purpose

Detecting and intervening in stress are crucial for sustaining overall health and well-being. Long-term stress can lead to the development of various physical and psychological disorders. Early identification and timely therapeutic treatment can mitigate these harmful effects, preventing the progression of stress-related conditions.

Evidence-based stress management interventions, such as cognitive-behavioral therapy, mindfulness-based stress reduction, and external influences like visual and audio stimuli, have been shown to effectively reduce the risk of stress-related disorders. This underscores the necessity of incorporating stress assessment tools and therapeutic interventions into routine health evaluations and wellness initiatives, highlighting the importance of proactive stress management in maintaining overall health.

The aim of this study is to present a novel approach for quantifying stress levels and delivering timely therapeutic interventions. Our device, integrated into a wearable platform, employs an array of physical sensors to monitor Electroencephalography (EEG), Electrooculography (EOG), electrodermal activity (EDA), and temperature (T). These sensors capture brain wave activities, eye movements and blink rates, skin conductance changes, and temperature respectively. By utilizing domain-agnostic meta-learning, we extract emotional features from these biological signals to predict stress levels.

Once the stress levels are quantified, the system selects and administers the most effective therapy from a range of options, including heat therapy, music therapy, and virtual reality (VR) therapy. This adaptive therapeutic approach ensures that the patient receives personalized and optimal interventions to alleviate stress. The integration of these advanced technologies into a wearable device offers continuous monitoring and immediate response, enhancing a closed-loop detection and management of stress in real-time.

# Objectives

The objective of this study is to develop and evaluate a novel wearable device designed to quantify stress levels and deliver timely therapeutic interventions. The device laminates on an ultra-thin and breathable Polyurethane (PU) substrate integrating physical sensors for brain activity, eye movements, skin conductance, and skin temperature measurements. With the biological information harvested, we aim to quantitatively establish correlations between physiological data with the subjective emotional stress levels followed by prompt therapy interventions. This study aims to demonstrate the efficacy of this integrated approach in providing continuous, real-time stress monitoring and intervention, ultimately enhancing overall health and well-being through proactive stress management.

# Study Design

## Device Fabrication

The device primarily consists of three components: an ultrathin substrate, intrinsically stretchable electrical interconnects, and ultrathin electrodes.

The fabrication process begins with the creation of an ultra-thin and breathable polyurethane (PU) substrate. This involves forming a thin film on a water-ethanol homogeneous solution. Once the film is formed, it is transferred onto a rectangular frame, providing the necessary structural support for subsequent steps.

Next, the electrical interconnections and temperature sensors are fabricated. The interconnections, which include resistive heating elements, are made from liquid metal/PU-based composites, while the temperature sensors are made from carbon nanotube (CNT)/PU-based composites. These components are precisely patterned using a laser cutter.

Physiological sensors are developed using a silver nanowire/PU composite. Similar to the substrate, this composite is fabricated on the water-ethanol surface and then laser-patterned.

Finally, all the individual components—including the electrical interconnections, resistive heating pads, physiological sensors, and temperature sensors—are assembled onto the ultra-thin PU substrate. This assembly process uses water-soluble tapes, which facilitate the transfer and integration of the components without compromising the substrate’s ultra-thin and breathable properties.

The fully assembled patch is then worn on the patient’s face, similar to applying a face mask.

## Protocol w/ commercial electrodes

Data acquisition can be performed using 3M Red Dot monitoring electrodes. The placement of these electrodes must align with the designated positions on the patch to ensure accurate measurements.

* **EOG Electrodes:** Placed at the left suprabrow region and the infraorbital region, aligning vertically with the left pupil. The EOG reference electrode is positioned right above the glabella region.
* **EEG Electrodes:** Positioned adjacent to the EOG reference electrodes on both sides. The EEG reference electrode is placed to the left of the zygomatic bone region.
* **Galvanic Skin Response (GSR) Electrodes:** Two electrodes are placed next to each other below the EOG reference electrode but slightly above the glabella region.
* **Temperature Sensors:** Laminated onto the heating pads, which are placed at the temple regions. An additional skin temperature sensor is positioned in the infratemporal region.

Once all the electrodes are mounted, patients are asked to isolate themselves from environmental noises and other external factors that might affect their emotional response. They are instructed to focus on their feelings before several experiments are conducted. Each experiment lasts approximately three minutes, followed by an anxiety questionnaire.

The procedure begins with collecting baseline signals, followed by an experiment designed to induce stress, specifically the cold pressor test (CPT). After the CPT, an appropriate therapy method (heat, music, or VR) is applied. Baseline and CPT measurements are repeated along with the therapy. Finally, the physiological data and questionnaire responses are analyzed by the machine learning model to quantify changes in stress levels.

## Protocol w/ ultrathin patch

The ultrathin stress monitoring patch is worn on the patient’s face, with precise electrode placement ensured by aligning the EOG electrodes vertically across the pupil and positioning the EOG reference electrode above the glabella region. Wireless data collection and transmission are achieved by connecting the patch to an external circuit board.

Once the patch is securely worn and the external circuit board is mounted, patients are asked to isolate themselves from environmental noises and other external factors that might affect their emotional response. They are instructed to focus on their feelings before several experiments are conducted. Each experiment lasts approximately three minutes and is followed by an anxiety questionnaire.

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