Doze: Hydrogel-Based Epidermal Platform for Personalized Scent Diffusion

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Figure 1: Presentation of the experiments, design evolution, and final prototype.

ABSTRACT

Doze is an on-skin, hydrogel-based sleep mask which seeks to improve, enhance, and augment sleep through the use of programmed scent diffusion in tune with the user's cortical rhythms. Taking advantage of hydrogels' unique properties, the Doze mask encapsulates and emits therapeutic scents at a regulated pace. The release of scent is controlled by an embedded heater within the layers of the mask and communicates remotely to a smart device. This communication allows for a personalized dosage release based on the user's biometric or contextual data. Investigating both the pervasive power of smell in enhancing sleep as well as natural topical remedies, this personalized mask explores the potential for unintrusive solutions to the ever-growing rarity of a good night's sleep.

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CCS CONCEPTS

• Human-Centered Computing • Applied Computing

KEYWORDS

Hydrogels; Sleep Mask; Drug Delivery; Scent Diffusion; Wearable Technology.

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1 INTRODUCTION

Sleep deprivation impacts an estimated 83.6 million U.S. adults, is associated with greater likelihood of obesity, high blood pressure, diabetes, and heart disease, and represents a $28 billion market [1]. Sleep masks improve sleep quality, but are limited in their utility, and fail to adapt to user needs. The purpose of this work was to develop an eye-mask that improves sleep through responsive design and olfactory stimulation.

We plan to address this through the modernization of the sleep mask. While maintaining its original form and function, we present a biocompatible, unobtrusive on-skin adhesive in addition to scent activation based on the user's biometric feedback. Doze introduces adhesive hydrogels [2], as a form-fitting method of attaching the sleep mask to the user's face, while providing direct application of scents and the potential for topical therapies onto the skin. This is an improvement on current eye mask designs, which generally rely on elastic bands looped around the head.

As the sense of smell plays a critical role on neurological impact [3, 4, 5], the necessity for alternative scent diffusion devices is increasing. It has been discussed and shown that memory reactivation [6], sleep patterns [7], and dreams [8], may be modulated by controlling scent diffusion. The Doze face mask integrates scent to enhance, promote and augment sleep. The focus on sleep improvement has become central for many new products on the smart device market, including *Dreem* [9], *Re-Timer* [10], and *THIM* [11]. *THIM*, for example, uses vibration to condition which sleep cycle you are in and brings you in and out of wakefulness, while *Re-Timer* looks to techniques of light therapy to prepare your body for sleep as well as increases alertness when awake. However, the introduction of smell has not yet been incorporated into these sleep augmentation devices. This work explores the power of combining the promising findings in olfactory therapeutics [8], sleep rhythms [7], and adhesive hydrogels [12]. Thus, we present *Doze*, an on-skin wearable in a sleep mask form-factor which releases personalized scents throughout the night based on the user's preference, desired performance, and sleep rhythms.

2 METHODS AND PROTOTYPE

We explored materials that matched the unique properties required by our designs and were also inexpensive. Due to the diverse capabilities and growing applications of hydrogels within the cosmetic industry, we felt this substrate satisfied our criteria for an on-skin sleep mask.

2.1 System Technology

Hydrogels are hydrophilic, three-dimensional polymeric matrices that are able to absorb and swell with water. Depending on the applications, stimuli-responsive hydrogels can be modified in terms of its material and mechanical structure, composition, biodegradability, release and loading properties [13, 14]. In this case, we leverage thermally-sensitive hydrogels that increase their water-solubility as the temperature increases, releasing the scent-infused liquid and evaporating it to the air. We used a light-weight, flexible polyimide heater pad with copper trace (Icstation) rated at 8.3 Ω, 2.5W and with a size of 3 by 4 cm as a base and laminated the scent-infused hydrogel on top of the heater. The heating element is connected to a microcontroller (Arduino Nano) and powered by a lithium polymer battery for programmable actuation of the hydrogel scent release.

2.2 Prototype Design

The prototype consists of two parts: the *Mask* and the *Therapeutics*. Within these two parts are multiple layers integrating the technology, scent infused hydrogel and adhesive face mask. The *Mask* holds the "permanent" components, and is made of a soft, porous material that encloses the battery and circuit board controlling the heater. These are made of small and flexible systems in order to make them seamless with the top layer of the mask. Envisioned as a separate package, *Therapeutics* would hold "single-use" sets of hydrogel insertions, pre-embedded with your personalized scent. The scent-infused hydrogel would be separated by a piece of material which would prevent eye irritations while also adding a "black-out" layer for light (Figure 2, 3).

Figure 2: Concept illustration of the two separate parts of the mask.

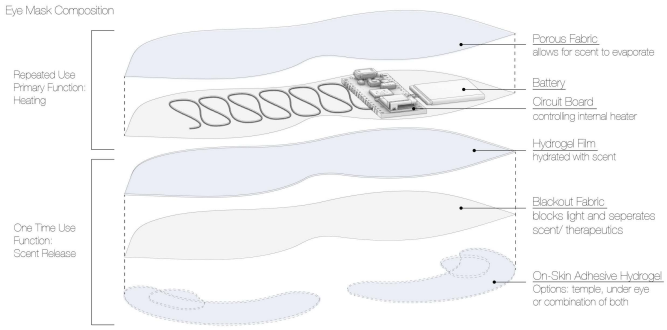

Figure 3: Exploded diagram illustrating each layer of the mask.

2.3 Prototype Execution

Ecoflex (Smooth-On), PDMS (Dow Corning) and generic hydrogels were used throughout early prototypes, as easily available substitutes for the composite hydrogels used in later= stages of development. Generic hydrogels used include generic superabsorbent diaper polymer and floral water pearls.

In initial stages of prototyping we explored the interactions between hydrogels and different container materials, experimenting with the rates of diffusion for fabrics of various weaves, materials and porosity, including cotton, linen, silk, nylon/polyester blend, spandex, merino wool, and mesh. Silk was selected as the most appropriate material for further prototyping due to its comfort and appropriate diffusion rate.

Molds for the composite hydrogel prototypes were fabricated using laser-cut acrylic pieces based on conventional eye mask geometries and targeted areas of the face for topical treatments (under-eye and temples). We prototyped different methods of integrating hydrogels with fabric, including weaving, screen printing, direct adhesion to skin, embedded magnets, ferro powder, and layering in between sewn fabric. The final prototype uses two layers of disposable hydrogel insertions, for separation of scent and drug delivery. One is layered in-between sewn fabric, while the other utilizes hydrogel's adhesive properties to attach the mask.

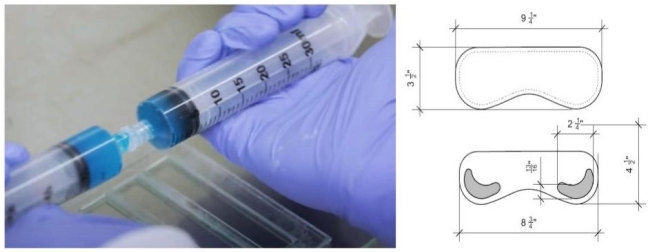

Figure 4: Mixing the hydrogels and scent (left). Mask and mold dimensions for fabrication (right).

3 EXPERIMENTS AND RESULTS

To prepare a tough hydrogel in the form of a preformed patch, alginate-polyacrylamide hydrogels were synthesized. In brief, sodium alginate and acrylamide were first dissolved in HBSS at 2% and 12% respectively and stirred overnight until a clean solution was obtained. This solution of 10mL was then mixed with 36µL of 2% covalent cross-linker MBAA, 8µL of accelerator TEMED, 226µL of 0.27M initiator APS, and 191µL of 0.75M ionic cross-linker CaSO4 slurries. The mixture was gelled inside a closed glass mold at room temperature overnight [2].

3.1 Detection of Odor Compounds

In order to characterize the quantity of odor release, we developed an automated, controllable system that consists of MQ2 (high-sensitivity to combustible gas), MQ3 (alcohol), MQ4 (methane, propane, and butane), and MQ8 (hydrogen) gas sensors placed in a sealed container with a heating element at the bottom (Figure 5a,b). A temperature profile (FLIR Duo) was also captured to accurately measure the temperature on the flexible heating pad. The system is connected to a microcontroller (Arduino Nano) that simultaneously reads and records all of the sensor data overtime, and actuates the heating element with a driving circuit powered from the lithium-polymer battery (3.7V). As can be observed in Figure 5c, odor compound release with the majority of alcohol concentration of the scent-infused hydrogel increases and forms a peak as we simulate an overnight actuation with a frequency of one release per hour. Finally, we also embedded a larger heating pad (Wirekinetics) with a size of 15 by 4 cm and rated at 25 Ω, 1W for our sleep mask prototype (Figure 5d).

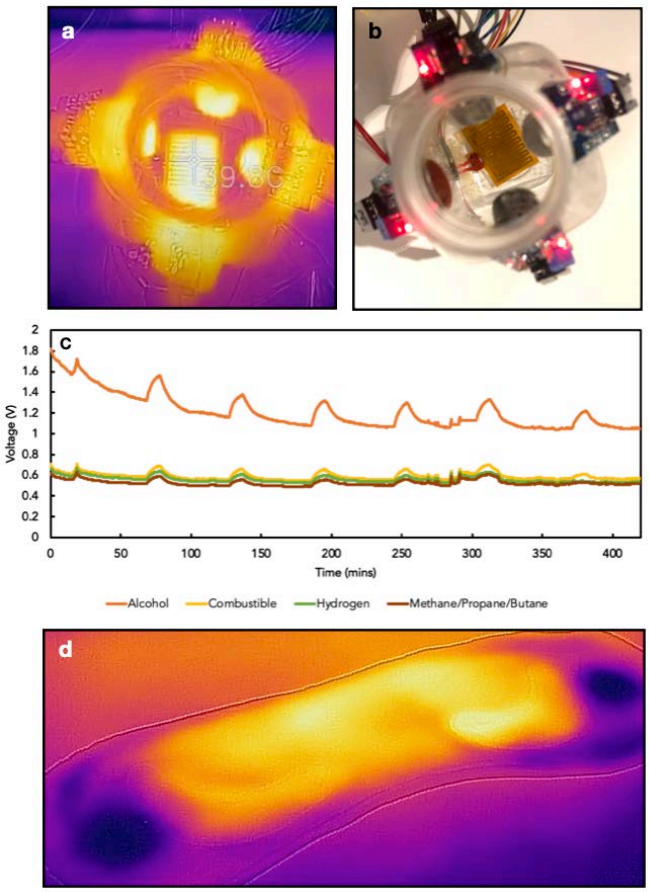

Figure 5: Scent diffusion setup characterization a) heat-map and b) digital capture, c) overnight preliminary characterization with hourly thermal actuation, and d) A sleep mask with an embedded heater.

4 CONCLUSION

Doze is a personalized scent diffusion wearable for enhancing sleep. Considerable research has been conducted on the link between the olfactory network and sleep, and our research builds on this literature to present a novel, hydrogel-based sleep aid [15]. Our findings demonstrate the Doze system has the capacity to modulate scent emittance based on pre-programmed conditions or biometric response.

Hydrogels infused with scent and actuated through a responsive heating element could take on a wide range of form-factors. Our early prototypes explored apparel to combat body odor, an on-skin patch for the diffusion of perfume or a personal fragrance, and responsive jewelry for scent emittance. Additional testing and research are needed to validate these use-cases.

Previous research demonstrates hydrogels can be engineered to absorb and emit topical pharmaceuticals [16, 17]. Although beyond the scope of this project, this precedent suggests the Doze system could be leveraged for epidermal drug-delivery. Future research on the Doze system will continue to explore this domain, including developing full wireless systems, integrating closed-loop physiological sensing and scent actuation, user-study design and implementation, and further experimentation with sleep aids such as melatonin or cannabidiol, as well as on-skin topical creams and cosmetics.

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