Note from the Editorial Board

Dear Reader,

The development and implementation of new and improved technologies has always served as a powerful guiding force for the course of human development. Over the past few decades, the pace of innovation has increased to a degree that is difficult to fully comprehend. The gadgets that seem to drive so much of daily life are made continuously more accessible, sleeker, and more powerful, even while new products and concepts are brought to market on a daily basis. Moore’s law describes this sort of rapid proliferation well for computing hardware; since the early 1970s, available computing power, as judged by the density of transistors contained within a dense integrated circuit, has roughly doubled every two years. Since computing power drives a great deal of technological development today, Moore’s law has also been observed to apply fairly well as a predictor for the rate of innovation more generally. As computers continue to be made exponentially more powerful, the gadgets that they power make great leaps in complexity and utility at a rapid pace.

This issue of the DUJS strives to highlight a small subset of gadgets that have positively impacted the course of human development in a variety of areas. Stephanie Alden describes the ways in which surgical simulations can improve surgical outcomes. Mulin Xiong highlights recent advances in 3D printing technology. Hae-Lin Cho chronicles the rise of a variety of “wearable” technologies that incorporate the human body as an element of gadget design. Ali Siddiqui hearkens back to one of the earliest known gadgets, the Antikythera mechanism, making note of the ways in which the ancient technology was ahead of its time. Melvin King discusses the rapidly growing field of tablet technology. Merritt Losert walks through the history of the touchscreen and addresses the inner workings of the touchscreen today. Stephen Ofori notes the power of recent advances in retinal prostheses to restore some elements of vision in the blind. Jessica Barfield describes a movement toward “digital tattoos” as a way to collect information about the human body and its function through the skin. This issue’s faculty interview features Lorie Loeb and a bit of background on the many projects that pass through the Digital Arts Leadership and Innovation (DALI) lab at Dartmouth College.

This issue also features three original research submissions. Alexa Krupp, Rebecca Novello, and Ellen Plane of Dartmouth College describe foraging behavior in insectivorrous bats. Kelly Brennan of the University of Florida examines how well preeclampsia can be predicted through plethysmogram analysis. Finally, Philip Mannes, Ahsan Kamal, Jordan Harvey-Morgan, and Kirby Spivey IV of Dartmouth College use High-Performance Liquid Chromatography (HPLC) and UV-Visualization Spectroscopy to characterize compounds that absorb light in the ultraviolet spectrum.

This issue of the DUJS would not be possible without the diligence and dedication of the writers, editors, staff members, and faculty advisors. We would like to thank all of those involved in maintaining the journal’s continued success as an outstanding undergraduate scientific outlet.

Thank you for reading the DUJS, and we hope you enjoy the issue.

Sincerely,

Andrew T. Foley
Editor-in-Chief
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## ORIGINAL RESEARCH

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Faculty Spotlight:

Lorie Loeb
Director of the Digital Arts Program and the DALI Lab

BY STEVEN CHEN

Could you tell me a little about the DALI lab?

The Digital Arts Leadership and Innovation lab (DALI) brings together designers, developers, and project managers in small teams to work on real-world problems. We use elegant design and state of the art technology to communicate complex information. We offer students an opportunity to use the foundations of learning they get in their liberal arts education and bring them into practice. Along the way they learn skills they don’t get in a classroom—programming for web and mobile.
applications, UI/UX design, project management, effective communication, and teamwork. Problem solving is at the core of what we do. Students first learn how to frame a problem by asking critical questions and changing mindsets, and then they learn methods for answering those questions using technology and design. In other words, before we start making solutions we have to understand what is it we’re trying to do and why we’re trying to do it. That is the human-centered design piece of our work. It is, in many ways, the key to the success of the lab. The fun part is that we pretty much throw the students into the deep end with these problems and then do what we can to help them learn to swim. It is a lot of independent learning, but in a safe and supportive environment.

How did the DALI lab get started? Where do you see it going in the next few years?

I’ve been [at Dartmouth] for 12 years, and I come from an arts background, but I’ve been working in computer science for quite some time. When I came here, I started doing some projects with students that combined art and technology. More and more people have been coming to us and asking us to be involved in different projects. It seemed it would be beneficial to make it more programmatic, so, a year and a half ago, I approached Dan Rockmore (Professor in the Math Department and Director of the Neukom Institute). With funding from the Neukom Institute and the support of the Computer Science Department, Dan Rockmore, Tim Tregubov, and I started the lab. We are funded through the end of the summer term in 2015. We’re hoping to get additional funding, and we feel confident we will. We have worked on over 50 projects and had around 140 student members in the lab so far. We calculated that at this rate, five percent of the Dartmouth student body will work at the DALI lab at some point. We have around 60 students each term, most of them stay on for multiple terms and even multiple years. The DALI Lab is, I believe, a great example of experiential learning, which is something President Hanlon has been working hard to bring to Dartmouth. I hope our work can continue, and become core to the educational experience for even more students.

Where do the students who work in the DALI lab come from? What kinds of backgrounds do they have?

Many people tell me the lab is one of the most diverse spaces on campus. Students are coming from all over the College and from all over the world. The largest group of students major or minor in computer science, but others major in studio art, engineering, math, economics, psychology, cognitive science, biology, film and media studies. One thing we are very proud of is the number of women in the lab. Approximately 50 percent of the students in the lab are women, which is extremely unusual in the STEM topics.

Can you describe some of DALI lab’s projects?

One of the first projects we did was for the U.S. Holocaust Museum and the Center for the Prevention of Genocide. It’s called the Early Warning Project. Ben Valentino, Professor in the Government Department, brought the project to us, and the Dickey Center for International Understanding was also involved. They’ve been working on the statistical models to assess the risk of the next atrocity—defined as one thousand or more civilian deaths in a short period of time by an organized group. They had been looking at different indicators for several years and were sharing it with various agencies in the U.S. government. There was a desire to make the models public: to give that information to human rights groups and other governments so they can act on the information, and also to provide a place where they can get new information to make their models even stronger. So we created a web application that is being launched in November of 2014. We created the prototype, which was completed in spring 2014.

We also did a project with Tom Luxon, Professor in the English Department. He has this project called the Milton Reading Room, which is an online annotation of Milton’s work. It gets about 64,000 hits a day. It was a beautiful site in terms of content, but it was made with old and outdated technology. We revamped the website for him, both the look and the technology
used, and it is quite effective.

We are currently working on a project with Professor Kofi Adami in Thayer. The project involves building a COPD monitor. Our students designed the look of the monitor, which will be a device with a microphone that rests on the chest. We are working on the signal processing so the device will be able to differentiate between a cough and a wheeze and building a smartphone app that will collect information and give feedback to the person on how they’re doing.

We also have the opportunity to work with start-ups, other non-profits and museums, and faculty across campus on a wide range of projects that have us designing and building web-applications, mobile apps and games, wearable technologies, 3D printed and smart fabrics, virtual reality applications (a project funded by NASA, to help with depression and conflict during long-duration space flight), and interactive installations. It is very exciting. I receive around three requests per day from someone who wants to work with us on a project. There is a long waiting list.

How do you determine which projects to take on?

We work on around 20 projects a term. People come to us through the Neukom Institute or through word of mouth. We have a vetting process. We are looking for projects that have a mix of interesting technology and design challenges, big impact, social justice applications, and a coolness factor. We also have an event called “The Pitch”. The Pitch is an opportunity for students, staff, and faculty to pitch their ideas in two minutes. We want to know what the impact value is rather than the business model. This year we are teaming with DEN (Dartmouth Entrepreneurial Network) to do The Pitch in the fall, winter and spring terms. Winners receive a cash stipend, design assistance, development help and/or venture advice and support. Last year’s Pitch had 33 people pitch, which was incredible. We had faculty, staff, students, PhDs, and post-docs from every part of the campus—from the medical school to Thayer to Tuck to the College itself. The Pitch is a good way to get support from DALI and DEN.

What kind of research do you do outside of DALI Lab?

I look into developing interfaces and systems that motivate people to change their behaviors. 100,000 hours of YouTube videos are uploaded every minute. There are over 7 billion websites. How do we break through all that information and noise to catch people’s attention, and then, once we have it, how do you motivate them to do the right thing (conserve resources, break bad habits, take care of themselves)? You could call this data visualization, or UI/UX design, behavioral economics, storytelling. It is a rich and complex area of study filled with unsolved problems. I like those kinds of hard challenges.

Which courses do you teach?

I teach courses in the Digital Arts minor: the computer animation class, the 3D modeling class, the culminating experience course for the minor where students complete a project, and a graduate level reading course.

How can students get involved in the DALI lab or in the Digital Arts minor?

If they want to get involved in the Digital Arts minor, they should take a course! There are two great visiting professors who also teach courses in the minor (Pat Hannaway and Jim Mahoney), and Michael Casey (Professor in Digital Musics and CS) teaches the programming for digital arts course. I’m always happy to talk to students too. The classes get filled quickly and we are trying to add sections and courses to accommodate the demand. People can see all kinds of cool digital things (from our courses across campus) at DMAX, the Digital Music and Arts Exposition, which is generally held in late April or early May at the Hopkins Center.

If students want to get involved in the DALI lab, they should apply at dali.dartmouth.edu. Students can also attend our workshops that are open to a wider group of students.
Introduction

While there is evidence to support that humans engaged in practices that could be characterized as "surgery" as early as 6500 B.C., practices that resemble modern surgery are far more recent in origin. Scientific surgery, with trained surgeons and an advanced understanding of human physiology, did not begin until the early 1900s. Even in the early 20th century, surgical techniques were primitive and unsanitary by today’s standards. In the first half of the twentieth century, surgical methods improved greatly, often through practice using simulators such as cadavers and animals (1).

It was not until the 1960s that the first modern surgical simulators, now mostly electrical and software-based, were created. The prototypes for the most effective simulators used in research hospitals and universities today, including virtual reality and mannequin-based simulators, were not developed until the 1990s (2).

The Development of Surgical Simulation Technology

Part-task trainers were the first surgical simulators created. These simulators model a portion of the human body and, as a result, help doctors develop a very specific set of technical skills (3). Toymaker Asmund Laerdal and physician Peter Safar created the first simulator of this type, called Resusci Anne, in 1960. This model contains both the face and the upper body of a female, with a springboard chest that allows for more lifelike interactions, and is still widely used for CPR training today in somewhat enhanced versions. Further improvements led to the Harvey mannequin, created in 1968 at the University of Miami, which mimics the human cardiovascular system, including a variable pulse and blood pressure (2).

These early part-task trainers, coupled with the development of computers, paved the way for more advanced technologies, including full-sized replicas and software systems. In 1986, the National Institute of Health’s National Library of Medicine (NLM) created an accurate three-dimensional representation of the human body using CT scans, MRIs, and cryosection imaging of human cadavers in what is officially called the Visible Human Project (2,4). Using these to more accurately represent the human body, developers created two-dimensional computer-based virtual reality and haptic systems, as well as integrated simulators, among other surgical simulator types (3).
Types of Surgical Simulators

Although many different types of simulators have been developed throughout the 20th and 21st centuries, three of the major simulator types used and still under development today are: virtual reality simulators, haptic systems, and integrated systems.

Virtual Reality

In virtual reality simulation, surgeons can “interact with 3D computerized databases in real time using their natural senses and skills” (5). With graphical displays that use 25 to 30 images per second to recreate continuous motion, surgeons can practice with virtual scenes in real time, and, in turn, machines can track surgeons’ movements “with submillimetre accuracy” to make the experience more realistic and informative (6). In many virtual models, patient characteristics such as fat and muscle mass can be altered to give surgeons experience with a variety of patient types (7).

For example, the Minimally Invasive Surgical Trainer (MIST) system, developed by Mentice Medical Simulation AB in the 1990s, helped practitioners develop their skills in laparoscopic surgery, in which internal organs are viewed and operations are performed via insertion of a small tube through an incision made at the surface of the body. In this system, 3D computer graphics recreate organs that would be seen on a computer screen during an actual laparoscopic surgery, and the movement of instruments within the system can be tracked and displayed on the screen as well (5). Since developing the MIST system, Mentice has upgraded to the VIST-C, an endovascular simulator that incorporates devices used in actual procedures, such as syringes and inflation devices, and allows for practice with techniques ranging from vascular repair to valve implantation (8).

Haptic Systems

To enhance virtual reality simulators, innovators have paired them with haptic systems, which provide the trainee with force and tactile feedback using input/output (I/O) devices that allow for bidirectional interactions between trainees and processors (9). With the number of laparoscopic surgeries increasing, the ability to recreate these tactile aspects is becoming more essential.

Particle-based and finite-element models are used to reconstruct the interaction between organs and instruments that occurs in real procedures. In particle-based models, components of an organ are connected to one another using dampers and springs. Each particle, and thus each part of the organ, has its own properties and movements when acted on by a user. In contrast, in finite-element models, the elements of the surface and volume of an organ are separated, formulated, and later combined to process organ deformation using a number of differential equations (9).

Many innovators also use shape memory metals, which can remember their initial shape and return to their original conformation when heated. Researchers have also incorporated electrorheological fluids, which exhibit viscosity changes in response to the application of an electric field, to provide users with a more realistic experience (7).

In addition, piezoresistive tactile sensors, which use changes in electrical resistance to convey the force applied to the sensor, are now used to determine the softness, stretch, and strength of tissue. These sensors contain a plastic plate bordered by force sensors on either side; as pressure pushes these plates together, the sensors relay information regarding the pressure applied and the return pressure necessary to move the detected object a certain distance (10).

In order to keep up with the increased firing rate of biological receptors in the human body,
processing systems must work at a rate up to 30 times faster than visual feedback systems used in virtual reality simulators. As a result of the high computational power required, however, simulator accuracy must often be sacrificed to obtain the desired level of high-speed returns (7).

**Integrated Systems**

Finally, integrated systems, also known as high fidelity human patient simulators, use a software-based system along with a life-sized mannequin to give training physicians a realistic imitation of open procedures (2). These systems were initially popular in training anesthesiologists, with a complete mannequin system that combined a Comprehensive Anesthesia Simulation Environment (CASE) with mathematical models that could synthesize and process this information (3). CASE reproduced the physical characteristics of an actual human such as breathing, blood pressure, and oxygen levels. These values could be read and evaluated to determine the appropriate medications for use during surgery (3). Later, as other specialties acquired interest in this technology, human patient simulators become both more widespread and more advanced, with dozens of models from companies around the world on the market today. CAE Healthcare, a medical simulation company, created the Human Patient Simulator with lifelike cardiovascular, respiratory, and neurological systems. The Human Patient Simulator has the ability to "accurately represent complex surgical, critical care, and drug interaction scenarios," as well as to facilitate true O₂ and CO₂ gas exchange (11). CAE Healthcare’s model called Caesar can hold over a liter of blood, allowing the simulator to recreate severe bleeding; Caesar can also respond to tourniquet application appropriately (12).

Finally, iStan, another CAE Healthcare product, has independent right and left lungs, allowing the simulator to recreate serious respiratory complications (13). iStan’s blood pressure, oxygen levels, and other physiological signs can change automatically in response to bleeding and medical treatment, making iStan one of the most realistic integrated simulators on the market (13).

**Implications**

While surgical simulators are a popular area of technological development, their value has been called into question. Multiple studies have been conducted to determine if these simulators actually improve surgeons’ performance, and many recent analyses suggest that they do.

For example, a study of surgical residents at Queen’s University, Belfast and Yale University showed that Mentice’s MIST system, discussed above, improved performance by reducing the error rate during laparoscopic cholecystectomies, a surgery to remove the gallbladder, by 80 percent and operating time by 29 percent, as compared to a group that only received standard programmatic training (14). A separate study evaluated the performance of surgery residents at McGill University after...
training with Fundamentals of Laparoscopic Surgery simulator training program. Researchers found a similar conclusion; residents who completed this program scored higher on metrics such as bimanual dexterity, tissue handling, and depth perception than did residents who did not complete the program (15).

Conclusion

While surgical simulation technology is still relatively new, it is advancing rapidly. From virtual reality simulators to human patient simulators, there are many different surgical simulator types that can be used by many different specialists. Improvements in computational power and materials science will only allow for the creation of more realistic simulations, providing surgeons with more practice before they reach the operating room.

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References


Figure 4: Federal Emergency Management Agency (FEMA) workers practice on a Caesar patient simulator. The Caesar simulator can simulate bleeding, eye movement, pulse, breathing, and speech, among many other physiological responses.
Introduction

Once a futuristic idea limited to the pages of science fiction, three-dimensional (3D) printing technology has reached an astounding level of accessibility. Anyone with a few thousand dollars and a downloadable online blueprint can now produce their own 3D creation. 3D printing, also known as additive manufacturing, describes the process of creating a 3D object from a model or electronic data source (1). Layers of materials are laid down to form the final product in an additive fashion using a variety of methods. As these methods have advanced over the years, the use of this technology has also become more widespread.

History of 3D Printing

While 3D printing has recently become widely known through mainstream applications, its history stretches as far back as the 1980s with the invention of stereolithography by Chuck Hull of 3D Systems Corporation (2). Stereolithography uses UV lasers to cure photopolymers, hardening or toughening the polymer through exposure to UV light, while building them layer-by-layer into a 3D object. This was the first example of additive manufacturing and, together with the STL file format used by 3D printing software, became the gateway to current 3D printing technology. In 1990, Stratasys commercialized the more recognizable plastic extrusion method, in which objects are created with a fixed cross-dimensional pattern, under the name “fused deposition modeling.” This was followed by the commercialization of “3D printing” by Z Corporation in 1995 with specific reference to the use of inkjet printing (2).

From the start, 3D printing was found to be useful in creating prototypes and visualizing data, as well as providing an alternative method of product development and manufacturing. Due to cost and efficiency restrictions, the process was not used for widespread manufacturing until recent years. As prices have dropped from $20,000 per machine in 2010 to less than $1,000 per machine more recently, sales of 3D printers have seen significant growth (3).

Basic Building Blocks

Although there is great variation in the process and application of 3D printing technology, all 3D printing technology consists of three basic processes. The first is modeling, which typically uses computer design software or a 3D scanner. The computer creates a geometric pattern that can be projected into a printable 3D model, translating physical objects into interpretable digital data. The difficulty of creating such models has given rise to a new...
market for 3D printed objects, with various companies competing to offer this new, advanced service (4).

Physical printing of the object follows modeling. "Slicer" software is used to process the model into thin layers and to convey precise instructions to the printer. The object is then assembled through stacked layers of the material, which are fused to create the final shape. Similar to photo resolution, printer resolution is described in dots per inch (dpi) or micrometers (μm), and the level of resolution depends on the abilities of the printer itself (5). Finally, to enhance precision, a finishing step in which the object is slightly oversized and then trimmed down follows the physical printing process (6). Although these three processes apply to most 3D printing methods, the specifics of each process depend on the materials used and the techniques used to add layers. Selective laser melting and fused deposition modeling use softened materials to create layers, while other techniques, such as stereolithography, use liquid materials. As a further example, laminated object manufacturing involves cutting thin, solid layers and joining them together into a final shape (7).

Applications and Impact

3D printing technology remained relatively dormant for many years due to slow printing speed, which limited its use in mass production. With recent developments, however, production efficiency has increased, while costs have dropped. 3D printers can now use multiple heads to print multiple colors, polymers, or prints simultaneously. An assembly line method also helps to streamline the production process, using multiple machines to create the simple components that compose each printer (8). With the increase in sales, applications of 3D printing technology have spread to the fields of architecture, industrial design, military, engineering, medicine, biotechnology, fashion, education, and even food.

The growing potential for the use of 3D printers in the home has led to a more serious consideration of their social and environmental impact. The ability to personally manufacture everyday essentials without having to rely on their purchase or delivery could eliminate current costs associated with manufacturing and distribution. Likewise, 3D printing could change the consumer culture for certain products, creating a market for 3D printing materials rather than the finished product (9).

In the realm of art and fashion, 3D printing has found its niche in producing a variety of consumer goods—from eyewear to gowns fit for a fashion runway (10). Various companies including LIX are exploring the use of 3D printing in creating new mediums of art through the invention of a 3D drawing pen, literally bringing another dimension to artistic creativity (11).

3D printing has also been useful in the dental, facial reconstruction, and artificial prosthetics fields, allowing for precise production of necessary components tailored specifically for each patient (12). Although such applications are already relatively well established, other areas such as the creation of patient-specific devices and organs for implantation have recently gained some traction. In 2011, surgeon Anthony Atala gave a TED talk describing preliminary ventures into the realm of 3D printed organs.

Figure 2: Jewelry is just one example of a 3D printed consumer good. The piece below is titled “Fashionista” and is made from printed glassfiber-filled nylon.
The creation of these organs involves the laying down of living cells in layers onto a gel or sugar matrix (13). Such methods could eliminate the current shortage of available and compatible organs needed for life-saving transplant operations, effectively removing the risk of transplant rejection by growing organs from the patient’s own cells. Although the use of 3D printing for organ creation is still under development, a customized titanium pelvis and lower jaw, as well as a plastic tracheal splint, have been generated through 3D printing (2, 12). Mainstream application of these innovations will require many more years of research.

Consequences of Advancement

One result of the rapid rate of development of new applications for 3D printing is that the social implications new applications must also be considered in rapid succession. One current issue is the use of 3D printers to create firearms. Defense Distributed, an online, open-source, U.S.-based organization, designed a working plastic gun in 2012 that could be produced by anyone with a 3D printer. They also created various gun components and distributed the first working blueprint of a 3D printed gun in May of 2013 (13). This liberal distribution raises new issues in the gun control debate. If the spread of 3D printed weapons becomes as easy as file sharing, any legislative efforts to regulate gun ownership and circulation would become considerably more difficult to enforce. Legislators have proposed restricting the functions of 3D printers to prevent production of dangerous and/or harmful objects, but no suitable solution has been found (14).

This technology also adds a wrinkle to the debate over pirating and file-sharing, expanding from digital internet files to the blueprints for physical objects that can be produced and distributed. In this regard, the question of how to apply patenting and manufacturing copyright has become more urgent. Patenting covers processes, machines, and composition of matter, but it is not all-encompassing in time or range. When it comes to inventions and innovations, functional and artistic aspects must be considered separately, which poses some difficulty for 3D printing since it allows for the creation of physical goods along a broad spectrum that ranges from largely functional to purely artistic (15).

Without a well-structured method of claiming ownership, the difficulties encountered in attempting to protect digital intellectual property could effectively spread to the physical realm.

Finally, the growth of 3D printing technology brings with it various other social impacts. New online social platforms provide consumers with support and resources including how-to guides, open source blueprints, and discussion forums. At the same time, the increasing popularity of this technology could have a potentially negative effect on the job market. Although the complete replacement of unskilled workers with robots is fairly unrealistic, as the efficiency of 3D printing improves, the number of manual labor jobs may soon decrease (3).

Conclusion

Regardless of the implications and potential consequences, it is undeniable that 3D printing is an innovative field that will change the world as we know it. From fashion to biotechnology, food to architecture, the possibilities for creation and exploration are endless. However, as 3D printing continues to develop rapidly, it may also prove important to keep one eye on the past. The purpose of technological advancement

“Regardless of the implications and potential consequences, it is undeniable that 3D printing is an innovative field that will change the world as we know it. From fashion to biotechnology, food to architecture, the possibilities for creation and exploration are endless.”
has always been to better the standard of living wherever possible, and the considerations for 3D printing are no different. By maintaining a unified goal, developments in the field of 3D printing will play their part in bringing about a better future.

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References


Figure 4: Parts for Defense Distributed’s Liberator gun, all of which were created from a 3D printer. In May 2013, the U.S. Department of State ordered the blueprints to be taken offline.
Introduction

Some aspects of life in the 21st century are undeniably easier than life in the past. Modern technology improves the quality of living for many by allowing for a more comfortable and less strenuous lifestyle. Despite all of the positive effects of technological development where the potential for comfort is concerned, these changes have also had unforeseen negative consequences that now threaten one of the most intuitive human priorities: human health.

For many reasons, obesity, diabetes, and their associated side effects are skyrocketing in the United States and around the world. The Centers for Disease Control (CDC) reports that more than one-third of adults in America are obese, and the number continues to rise (2). Along with obesity, diabetes has also become more prevalent in recent years. According to the International Diabetes Federation (IDF), more than 382 million people live with diabetes, and the trend shows no signs of fading (3). Jean Claude Mbanya, the IDF’s president, stated in 2011 that: “In every country and in every community worldwide, we are losing the battle against this cruel and deadly disease” (3). These two major problems, along with ever-present disparities in healthcare quality and access, have left many experts worrying about solutions. Both doctors and researchers agree that technology, specifically wearable technology, may have an important role in addressing obesity and diabetes, as well as a host of other chronic health conditions for which more abundant and accurate patient information can play a role in informing and improving treatment decisions.

What is Wearable Technology?

Depending on the definition, the origins of wearable technology can be traced as far back as the ancient Chinese abacus, which could be worn on the person in the form of a ring (4). From the earliest technologies, more complex wearables such as pocket and wrist watches were developed in the 18th and 20th centuries, respectively (5).

The invention of the transistor in 1947 caused wearable technology to rapidly advance over the next two decades. Ed Thorp and Claude Shannon developed the first wearable computer system in 1966 in order to win games of roulette. They designed a computer the size of a pack of cigarettes connected via wires to a series of micro-switches in their shoes that timed the wheel and increased their winnings by 44 percent (6).

In 1981, Steve Mann, known to some as the father of wearable technology, developed a wearable computer that allowed him to control photographic systems. It consisted of a helmet-mounted camera powered by backpack-mounted batteries (5). Since Mann’s
invention, many companies have gone on to produce increasingly complex products, from smartwatches to Google Glass (7).

Why Wearable Technology?

Although scientists and engineers continue to experiment with virtual realities, a significant portion of wearable technology exists in the field of healthcare.

Wearable technology can measure critical information like body temperature, pulse, blood pressure, and other vital signs that can be important in diagnosing and treating a variety of health conditions. Many doctors believe that measurements made by wearable technology may be more accurate than those made in the hospital, which can be significantly impacted by the stress of a hospital visit. Wearable technology can collect information even while the patient is at home, providing constant and ideally more representative data (8). For these reasons, doctors believe that wearable technology play an important role in addressing health conditions.

Focus on Fitness: Fixing the Obesity Epidemic

Since obesity has been shown to be correlated with an increased incidence of type 2 diabetes, heart disease, and stroke, researchers take the “obesity epidemic” very seriously. More than sixty-five percent of Americans are overweight or obese. While the government and media have continually emphasized the importance of both individual fitness and nutrition, researchers believe that lowering obesity rates will require effort on a much wider front (10).

This newfound focus on fitness and nutrition creates a relatively untapped market for technology companies to produce products that could help an individual lose weight or get in shape, like pedometers, fitness trackers, and most recently, smartwatches. Smartwatches can act as a secondary computer screen to provide more information than just the time, including biometric data like heart rate, miles traveled, and calories burned.

By 1946, the concept of a “smartwatch” already existed in the media. Chester Gould’s quintessential policeman, Dick Tracy, carried the first ever smartwatch—a wristwatch that could act as a phone, radio, and a television screen. Similar gadgets appeared on later popular television shows, such as Star Trek and Knight Rider (11).

The Pebble Smartwatch, released in 2013, became the one of the first successful smartwatches by incorporating fitness tracking (11). Since then, other companies have entered the market, including Motorola, Sony, Samsung, and Apple (11).

According to some researchers, however, headphones can gather a larger and more accurate variety of biometric data than wristwatches. For example, sensors in the ear, unlike wristwatches, can measure core body temperature. Since many people opt to listen to music while exercising or performing other activities, some manufacturers argue that headphones might even be less cumbersome for use.

Figure 2: Pebble E-Paper Watch. Pebble released one of the first successful smartwatches that included fitness tracking.
the wearer. In addition, smart headphones may be able to eliminate safety hazards associated with outdoor exercise by filtering unnecessary noises and magnifying important ones (12).

Since these technologies are relatively new, the degree to which they gain traction among the general public remains to be seen. However, research done by the Vitality Group indicates that wearable technology, especially when it is paired with an incentive or a “structured program,” can result in improvements in employee behavior, lower cholesterol levels, and decreases in body mass index (13).

**Tackling Diabetes**

The obesity epidemic has been shown to be closely linked to increasing rates of type 2 diabetes, which has grown to be one of the largest public health concerns in the United States. Diabetes is the seventh leading cause of death in the United States, and it has rapidly increased in prevalence over the past few years. While 8.3 percent of the population of the United States had been diagnosed with diabetes in 2010, that number rose to 9.3 percent in 2012 (14).

Diabetes comes in two forms, type 1 and type 2. Both hinder the body’s production and metabolism of the pancreatic hormone insulin, resulting in dangerous fluctuations of blood sugar levels that require immediate treatment to avoid severe complications, including diabetic coma and possibly death (14). Many people with diabetes, including everyone who is diagnosed with type 1 diabetes, rely on insulin injections to manage blood sugar levels. However, traditional insulin delivery requires multiple daily injections, along with finger pricks to measure blood glucose levels in order to administer appropriate doses (14, 15).

This need for regular blood glucose monitoring and insulin injection led to the design of several wearable technologies capable of measuring blood glucose using minimally invasive methods. Some diabetes patients use a continuous glucose monitoring system that can adhere to the abdomen and analyze blood glucose levels every ten seconds while providing output on a monitor that can be attached to the wearer’s beltline (15).

In an attempt to further limit the invasiveness of blood glucose monitoring, Google released a prototype smart contact lens early in 2014. The project aims to provide automatic blood glucose readings from fluid in the eye using a small chip and sensor embedded in the contact lens. The data would then be automatically linked to smartphone applications that serve collect, store, and analyze trends in the readings (16, 17). However, the prototype has yet to receive FDA approval due to possible concerns over lag in the glucose levels in eye fluid as compared with the blood (16).

This technology would decrease the hassle of regular, manual blood glucose readings. However, the ideal piece of technology for a person with diabetes would incorporate both the capability to measure blood glucose levels and the ability to administer appropriate doses of insulin to automatically adjust those levels without user input (14). While no such product exists just yet, considerable steps have been taken toward developing a wearable technology that can measure and control blood glucose levels within a set range. Ed Damiano, Associate Professor of Biomedical Engineering at Boston University, hopes to perfect a bionic pancreas with a blood sugar monitor that sends readings to an iPhone application. The application would respond to blood glucose readings by signaling one of two pumps to inject insulin or glucagon to lower or raise blood glucose levels, respectively.
Perhaps the most significant improvement in diabetes management so far is the advent of continuous glucose monitoring systems. The bionic pancreas, for example, is a device that imitates the continuous filtering performed by our kidneys and eliminates the need for frequent hospital visits. This can perform dialysis on end-stage renal disease patients (20). Artificial kidneys better imitate the continuous filtering performed by our kidneys and eliminate the need for frequent hospital visits.

Other Health Applications

Although much of the recent development in the wearable technology sector is focused on obesity and diabetes, other groups are developing wearable technology to address a variety of other clinical conditions.

Some smartwatches have been designed to diagnose and monitor Parkinson’s disease by tracking the speed and frequency of movement, which is one of its more obvious symptoms. The Michael J. Fox Foundation is currently running clinical trials on designs that can make 300 of these measurements per second. This rich data can provide not only a better understanding of the individual but of Parkinson’s as a whole (19).

In addition, other bionic organs like artificial kidneys are currently in development. These can perform dialysis on end-stage renal disease patients (20). Artificial kidneys better imitate the continuous filtering performed by our kidneys and eliminate the need for frequent hospital visits.

Conclusion

Like most significant problems, the obesity and diabetes epidemics cannot be solved with just one approach. Wearable technology, while making incredible headway in the field of health, will not be a panacea.

However, wearable technology remains a young field of research, and new potential applications continue to be identified. It offers a unique approach to addressing the obesity and diabetes crises that face the U.S. and many other countries, in addition to other health-related issues, and may soon become an integral part of solutions to these problems going forward.

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References


Figure 5: The bionic pancreas senses blood glucose levels and sends the signals to an iPhone app, which then raises or lowers glucose using the glucagon or insulin pump, respectively. Ideally, the patient would not need to worry about monitoring glucose levels or injecting insulin at all.

“Wearable technology, while making incredible headway in the field of health, will not be a panacea.”
In 1900, divers came across a shipwreck off the coast of the island of Antikythera (1,2). Among the wreckage was what seemed to be lumps of bronze encased in a wooden box (3). However, after some cleaning, researchers found the bronze to be an intricate device with many gears (4). The device dates back to the first century BC, but geared devices of a similar complexity would not appear again until the invention of clocks in medieval Europe and China almost a millennium later (2,4).

Due to age and corrosion, the device known as the Antikythera Mechanism broke into 7 large fragments and 75 smaller ones. To enable analysis without physical contact with the fragile fragments, researchers have used microfocus X-ray computed tomography or X-ray CT and polynomial texture mapping (PTM) to examine the mechanism (5). X-ray CT allows researchers to look at the insides of the 82 fragments, many of which contain pieces of the intricate gear system. PTM is used to light the fragments from different angles, which helps to enhance the color and texture of the surfaces of the fragments so that researchers can read the inscriptions on the fragments (5). Researchers have done three X-ray studies to determine the purpose of the mechanism.

After these analyses, researchers believe that the Antikythera Mechanism was contained within a wooden box approximately 326 mm by 164 mm by 48 mm in size and was most likely operated by a handle or a crank (2,5). The box contained instructions on how to operate the mechanism (2). From these inscriptions as well as the dimensions of the gears and dials, researchers have concluded that the Antikythera Mechanism could have been used to perform a wide array of astronomical calculations.

They have established that the mechanism contained a Zodiac dial that tracked the 12 Zodiac constellations. It also contained a movable calendar dial to account for the 365 days in a solar year. This dial could be adjusted to account for the fact that solar years are actually 365.25 days long, something that previous
Egyptian calendars did not account for. Two dials in the back are linked to the lunar cycle, with the upper dial representing the Metonic calendar. They match the calendar’s 235 lunar months and 19 solar year period. Within this dial are two smaller dials, one corresponding to the four-year Pan-Hellenic games cycle and the other representing the Callipic cycle. The Callipic cycle is a 76-year version of the Metonic calendar that is more accurate at corresponding lunar months to solar years (5,6). The other lower dial behind the back cover represents the Saros cycle, which predicts eclipses over 223 months. According to this cycle, similar eclipses occur after one Saros cycle (7). The inscriptions besides this dial help indicate the time when eclipses occur as well as the type of eclipse, while a smaller dial within helps further adjust eclipse times after the passing of each Saros cycle (4,5). The Antikythera Mechanism was also capable of tracking the position of the sun and the moon relative to the Zodiac and had a black and white stone that turned to reveal the phase of the moon on any given day (8). Inscriptions also imply that the device could note the time that the sun and the moon could be expected to rise and set on a particular day (9).

While it is clearly linked to the sun, the moon, and the Zodiac constellations, current research has aimed to discover whether the mechanism could be used to predict the orbits of planets as well. Some of the inscriptions explicitly name some of the planets, while other inscriptions that have been partially or completely lost may also refer to the planets (5). The relic currently has 30 gears, but the space between the front and back gears suggests that there might have been more gears to help track the motion of the five planets known at the time: Mercury, Venus, Mars, Jupiter, and Saturn (5,9). Researchers have proposed various models that add gear systems that accurately track all or some of these planets (1,2).

With or without planetary gears, the design of the mechanism is a testament to the skill and advanced knowledge of its inventor. The Greeks did not know at the time that the moon orbits the Earth in an ellipse, thereby slowing down and speeding up as it rotates around the Earth (2,8). However, the mechanism does account for this acceleration of the moon throughout its orbit through epicyclic gearing. This is the first known use of epicyclic gearing, and there is no evidence of its use in any technology until hundreds of years after the creation of the Antikythera Mechanism. Greek literature at the time made little mention of gear technology, and any mention did not elaborate on the sophistication of the mechanism (5).

The writings of Cicero describe both Archimedes and Poseidonius having devices that, like the Antikythera Mechanism, also tracked the motion of the sun, the moon, and the five planets (10,11). However, it is unlikely that either of the two scientists were directly involved in the version that has been recovered. The Antikythera shipwreck dates to around 70 BCE, but Archimedes’ device was last noted in Rome around 150 BC, and Cicero writes of seeing Poseidonius’ device around 45 BCE (2,12). Due to the similarities between the devices, it is likely that the inventor of the recovered mechanism based his device off of the work of these well-known scientists.

The inventor of the mechanism could have used his device for educational purposes, or he could have made it to satisfy his personal curiosity. The mechanism may have also been used for horoscopes, which was on the rise at the time of its invention (1). An individual’s horoscope depends on the positions of the Sun, the moon, and the planets at the time of one's birth, all of which may have been predicted by the mechanism. Additionally, the mechanism could be used to predict future fortunes and events, like eclipses (13). However, records show that astrologers of the time used prewritten tables for their predictions, making the Antikythera Mechanism seem more like an extravagance if it was used for astrology (1).
A great deal of mystery surrounds the mechanism, as there are few written records mentioning similar devices, as well as no physical evidence of other devices of its kind. It is quite possible that, due to shortages of metal at the time, similar devices were melted down and recycled (2). Since the timings of the Olympics and astrological predictions could have been coordinated by other means, there would likely have been little incentive for scientists to continue to produce devices as intricate and complex as the Antikythera mechanism (1).

Progress since the Antikythera Mechanism

Tracking of the moon and the planets has evolved greatly since the time of the Antikythera Mechanism. After Johannes Kepler discovered that planets move in mathematically-defined elliptical orbits in 1609 and Isaac Newton devised the laws of motion around 1687, calculations for eclipses and planetary position could be done using telescopes and appropriate distance parameters (14,15). Computer software can perform these calculations today, allowing for planetarium programs like Celestia, Stellarium, and Google Sky to provide us with views of our night skies on our computers or smart phones.

In addition, horoscopes no longer hold quite as much weight for most scientists. Instead, many astronomers try to track near-Earth objects like asteroids that have slim but historically real chances of colliding with the Earth. Since many of these objects are newly discovered, unlike the planets, their paths are often monitored by telescopes, both on and off the ground (16).

Unlike the Antikythera Mechanism, the personal gadgets of today are capable of many uses beyond the extraterrestrial. Instead of a crank, a few finger swipes or clicks of a mouse would allow one indirect access to the sky above and much else. Unlike the mysterious inventor of the Antikythera Mechanism, most consumers do not know much of the calculations involved in the gadgets they use to satisfy their curiosity of the stars. Many of us will continue to wonder at the advancements of the current age. Nevertheless, it is always nice to wonder what secrets of technology may be hidden, both past and present.

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References


“Computer software can perform these calculations today, allowing for planetarium programs like Celestia, Stellarium, and Google Sky to provide us with views of our night skies on our computers or smart phones.”
Advancements in computer technology inevitably result in computer hardware that is both smaller and faster. From the electromechanical switches of the 1930s and 40s to the integrated circuits of the 50s, computers have continually been upgraded to yield more computing power per unit of space. The culmination of this trend is the modern microprocessor, an integrated circuit responsible for powering the central processing unit (CPU) in all contemporary computers. The freedom from size constraints due to these microprocessors has resulted in the growth of new gadget markets, notably those of tablet computers and wearables such as the Google Glass.

**Tablet Popularization and Features**

Like many consumer gadgets, the development of tablets has largely reflected its intended audiences. Late 20th century tablets like the Apple Newton and the Palm Pilot were business oriented and antitheses of today’s mobile devices. They ran on custom operating systems and depended on pen technology for input (1). They were also expensive, too heavy for one-handed use, and plagued with software compatibility issues. Although almost every major tech company at the time, including Apple, Microsoft, Palm, and Nokia, participated in the fledgling tablet market, their inability to meet the demands of business users resulted in largely unsuccessful products (2).

The release of the iPad in April 2010 marked a change in the market’s audience. Its high resolution screen, lightweight (4.8 oz) frame, and access to the growing iTunes store combined to yield a device that was better suited for media consumption (3). Furthermore, its familiar design language, which caused many early critics to call it a “larger iPhone”, turned out to be an advantage. Anyone familiar with the iPhone, by far the most popular smartphone at the time, would know how to use the iPad. Today’s popular tablets mirror the iPad by adhering to the same basic principles: light frames, HD screens, and media support from Apple, Google, and, more recently, Amazon (4).

While current tablets owe much of their success to that of the first generation iPad, the iPad owes its success to the technology and business model of the iPod and iPhone (5). In particular, these devices were responsible for popularizing the use of capacitive touchscreens, which register touch based on the natural conductivity of human skin (6). This allowed smartphones and tablet operating systems to forgo the common “point and click” controls for more flexible multi-touch interfaces. Today’s near universal “pinch-to-zoom”, “swipe”, and “double tap” actions allow for a greater degree of manual control without the need for extra input options like buttons or stylus controls.

Another reason for the success of the iPad and other modern tablets is what many tech analysts call an “ecosystem” (7). Before
media libraries like iTunes and Google Play, music and video files had to be transferred by USB from one device to another. This process was tedious due to the size of the average music library and data speed limitations on USB cables. iTunes alleviated this problem by allowing users instant access to their media upon logging in and allowing purchases on any iTunes supported device to be enjoyed wirelessly on all of them. It is no coincidence that the most popular modern tablet brands such as the Galaxy Tab, iPad, and Kindle lines all have multimedia ecosystems backed by Google Play, iTunes, and the Amazon store, respectively.

The last key to a tablet’s usability is its processor. Generally, tablets are fitted with more powerful processors that generate less heat and consume less power than those in smartphones. Low heat generation is important for these devices since they do not have fans (8). However, this does not mean that current tablets are underpowered. Up-to-date tablets can simultaneously juggle web browsing, media streaming, mapping services, and other tasks. Some test processors are on par with lower level laptop processors and can run full versions of Microsoft Excel, Outlook, and Powerpoint.

The Future of Tablet Technology

The future of tablet technology is difficult to generalize because the market has differentiated greatly since the introduction of the iPad in 2010. For instance, the Kindle Fire has a 7” screen compared to the iPad’s 9.7” screen, and its processor is slightly slower. The Microsoft Surface Pro occupies another corner of the tablet market, as it is directed primarily toward the business consumer. The Pro includes a 12” display, a PC capable Intel processor, a full keyboard, and multiple USB ports. Categorizing tablets as a whole is complex, but predictions can be made by looking at new developments in the very similar smartphone market.

Although capacitive touchscreens offer an excellent degree of control, many major tech companies are currently experimenting with non-touch interfaces. Samsung has been particularly insistent on implementing gesture controls. The more recent iterations of its popular Galaxy S line of smartphones have infrared sensors capable of detecting eye, head, and hand movements in front of the screen. These offer a large number of custom actions like hand waving to switch between pictures and head bobbing to scroll down a page. While these features strike many critics as simple smartphone gimmicks, they could be useful when touching is undesirable, such as when cooking or eating (9).

By far, the most widespread form of non-touch manipulation is voice control. While flagship smartphones have typically supported a limited number of voice commands, the birth of Siri in late 2011 started the race for more accurate and intelligent voice control. Google followed with the launch of Google Now in 2012, and Microsoft followed with the release of Cortana in 2014. Despite different names, all of these personal assistants use a flexible natural language user interface in order to provide accurate responses to a large number of requests and questions (10). At the most basic level, the system simply responds with a Google search of the question. Voice commands are particularly useful when users have their hands full, as when they are driving. Voice control is also one of the primary interfaces used by Google Glass, a new wearable gadget.

Google Glass – Features, Specifications, and Potential

Google Glass is unique among wearable technologies because it is a head mounted device rather than a wrist mounted one, such as the Galaxy Gear and iWatch. Using an optical mounted LED display, the device pulls in content like smartphone notifications. Events like missed calls, weather information, photos, and calendar events can be scrolled.
through by using a touchpad on the right side of the device. Additionally, voice commands can be used to launch applications, including Maps, Gmail, and Google Now. The device even features a camera capable of taking photos and 720p HD video (11).

While most consumers are less likely to buy Google Glass because of its $1,500 price tag, the device has found use in military operations and health care. The government of Nepal uses Google Glass to prevent poaching in Chitwan International Park (13). Drchrono, a California based medical record company, has developed an application for Glass that allows physicians to have a head-mounted record of the patient’s medical history (14). In addition, Glass’s ability to communicate between users and integrate with other forms of technology, notably ultrasound, has led to its involvement in a variety of health-related experiments, including instructional surgery and foreign body identification (15).

Conclusion

While smartphones are somewhat limited in terms of form (most are lightweight and have screens smaller than 6”), tablet computers and wearables like Google Glass have taken on a variety of creative designs. Their freedom from this restriction allows them to represent the cutting edge of mobile technology. As is to be expected, the growth of the mobile technology market continues to yield devices that reflect evolving consumer desires.

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References


Figure 3: The Samsung Galaxy Gear is a smartwatch released in late 2013 by Samsung Electronics as a form of wearable technology intended to serve as a companion for other Samsung Galaxy products, including smartphones and tablets.
Touchscreens are everywhere. Smartphones with large touchscreen interfaces are abundant in the handheld phone market. Of the roughly 315 million people living in the United States, there were 144.5 million smartphone users in 2013, and that number is projected to grow to 220 million by 2018 (1). By the end of 2014, 1.76 billion people are expected to own and use smartphones monthly worldwide (2).

Phones are not the only devices employing touchscreens, however. For example, 195 million tablets like Apple’s iPad were sold in 2013 (3). Touchscreens are slowly filtering into the computer market as well. Touchscreen notebooks—hybrids of laptops and tablets that feature a large touch display—were forecast to take 11 percent of the laptop market in 2013 (4). Touchscreens have even migrated as far as watches and automobiles. Their widespread applicability makes it difficult to underestimate their importance to the technology industry today. This importance warrants a deeper look at the history, current function, and future of touchscreens.

The Evolution of Touchscreens

Touchscreens have not always been so widespread or functional. Their numbers only exploded after the release of Apple’s first iPhone in 2007, before which they were not widely available on the consumer market (5). In fact, the first consumer device with a digital display directly sensitive to touch, a music controller known as Lemur, became available in 2005. This device featured multi-touch capability but did not have the commercial impact of Apple’s iPhone (5).

Touchscreen technology has its earliest roots in the music industry (5). The first device considered to have touch-sensitive controls is a synthesizer called the Electronic Sackbut (5). Designed by Hugh Le Caine beginning in 1945, the Sackbut’s keyboard featured vertical pressure sensitivity to change volume and horizontal touch sensitivity to produce slides in pitch (6).

In 1965, E.A. Johnson developed what is often considered to be the first true touch screen. Manufactured by the Royal Radar Establishment of England for air traffic controllers, this device predates contemporary devices like ticketing machines and ATMs (5). The sensitivity of this screen arises from wires that run across the screen of a cathode ray tube connected to an A.C. bridge circuit. The electrostatic capacitance of the user’s fingers creates the touch signal (7).
Physicists at the University of Illinois became interested in using computers for learning, forming the Computer-based Education Research Laboratory in 1959. This group created PLATO, a computer-based education system (8). One iteration of the PLATO terminal, PLATO IV, released in 1972, was the first widely known device with a touch-based interface and was used regularly at the University of Illinois (5).

In the 1980s, touchscreen development accelerated. Nimish Mehta developed the first multi-touch device at the University of Toronto using video cameras to track hand movements. Also using cameras to track hand movements, computer artist Myron Krueger created a system for interacting with a computer through hand and body gestures. And in 1984, the first multi-touch screen was developed at Bell Labs (5).

Eventually, more consumer devices featured some form of a touchscreen. The Casio AT-550 watch, released in 1984, had a touch-based calculator feature. Users could draw numbers and operations on the watch face with their fingers to have the watch carry out an operation (9).

Touch technology first came to the telephone in 1993 with the release of the Simon personal communicator, developed by Bellsouth and Simon (5). This phone resembles a watered-down smartphone in several ways: the device could act as an email platform, a calendar, a scheduler, and a notepad (10).

After several other improvements in touch technology and the release of the aforementioned Lemur music controller and the first iPhone, the touchscreen took off. One need not look long to find a touchscreen on the phones, tablets, computers, and even automobiles that are widely used today.

How Touchscreens Work

By one estimate, 18 distinct types of touch technology currently exist (11). Describing each of these technologies is not feasible, but some types are more widely employed than others. In particular, two types of touchscreen are most common on the market today: resistive and projected capacitive (p-cap) touchscreens (11).

Resistive touchscreens consist of two layers—an inner layer of glass and an outer plastic film—on top of an LCD screen. A thin spacer separates these layers and a grid of conducting threads, often made of indium tin oxide, covers each layer (11). When someone pushes on the screen, they force the outer and inner grid of conductors to make contact, completing a circuit. A computer measures the resistance of this circuit to determine the

![Figure 2: Schematics of](a) Resistive touchscreen; the numbers stand for the 1. glass panel, 2. resistive coating, 3. micro-insulators, and 4. conductive membrane. (b) Projected capacitive touchscreen

location of the contact point on the screen (11).

Resistive touchscreens are cheaper and less sensitive than capacitive touchscreens and are often found on outdoor kiosks or ATMs, machines that only require the user to push large buttons (12). Because a conductive layer must move to complete a circuit, these screens are prone to wear and tear. A broken indium tin oxide thread, for example, would result in a dead spot on the screen (11). Moreover, due to the air gap between the glass and plastic layers, the screen must be thick, which is unsuitable for mobile devices, and the screen can have undesirable optical properties (11).

While resistive touchscreens measure electrical resistance, p-cap screens, as the name implies, measure electrical capacitance. In most p-cap screens, there are two conductive layers, again made of a grid of indium tin oxide wires, above the LCD screen and under a protective glass layer (11). These layers have slight charges, creating an electrostatic field. When a finger touches the screen, it acts as a capacitor, storing some of the electric charge on the conductors and changing this electrostatic field. Conducting threads can detect this change (12). Scanning each thread in the conductive grids separately allows a computer to register the coordinates of multiple contact points (11).

P-cap touchscreens have some advantages over resistive screens. First, they are more durable than resistive screens due to their lack of moving parts. P-cap screens are also much more precise, making them function well on mobile devices. Furthermore, they can sense multiple points of contact (11).

P-cap touchscreens do present challenges of their own, however. They are highly susceptible to noise, so devices using these screens need complicated software to distinguish clear signals (12). P-cap screens also have limitations on thinness; two layers of glass can add unwanted thickness (11).

The Future of Touchscreens

Currently, p-cap screens remain the most common touchscreens on the market, but variations of p-cap technology do exist in some devices. Some screens use a thin insulating layer instead of glass to separate the two conductive sheets, a method known as the “one glass solution.” Other screens use “on cell” p-cap, where the conducting sheet is built onto the LCD display itself. Others, including the iPhone 5, use “in cell” p-cap, where the sensor shares layers with the LCD screen (11).

P-cap touchscreens also have three-dimensional potential. As a result of their ability to measure minute differences in capacitance, they can detect fingers close to, but not touching, the screen. Some devices use this capability to detect if a phone is near a user’s face, but this proximity sensing has generally not been utilized. The potential exists for three-dimensional gestures, like the raising or lowering of a finger above the screen (13).

Touchscreens themselves are reaching into the third dimension as well. The same technology used in 3D televisions can be used on touchscreen displays. Researchers at
Immersion, a visual simulation company, have developed a three-dimensional touchscreen that can present multiple perspectives to multiple users, allowing more than one user to interact with a 3D environment in a realistic way. The display cycles rapidly between different images, each image representing one user’s perspective. Users wear 3D glasses, and these glasses have a built-in shutter. By synchronizing the shutter with the switching of images on the display, the glasses allow users only to see the image from their perspective (14).

Moving beyond simple interactions with a screen, researchers at Walt Disney Company are working on ways to actually feel a touchscreen in three dimensions. By blowing calculated pulses of air on a user’s hand, they can simulate the textures of an object. Other researchers at the University of Bristol in England are trying to create similar sensations using ultrasonic vibrations (15).

Lastly, touchscreens will continue to move beyond cell phones and tablets and into the world of everyday electronics. Home appliances, television remotes, and other such products will see buttons replaced with touchscreens. The applications of touchscreens are essentially endless, and consumers can expect to see them in new places with increasing frequency (13).

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References

“Touchscreens will continue to move beyond cell phones and tablets and into the world of everyday electronics.”

**Figure 4:** Disney is currently researching 3D touch screens where the user receives haptic feedback from a 2D image.
Introduction

Curing blindness has been a long-sought dream for humanity. However, most do not know that this dream exists in the form of an implantable device. Retinal prostheses are the result of advancements made in both surgical and biomedical technology. Progress in this field has been slow, and complete restoration of vision is not yet attainable. However, years of research have shown that retinal prosthesis is the best hope for restoring vision in the terminally blind.

Common forms of blindness: RP and AMD

Blindness occurs mostly due to ocular diseases that degenerate the photoreceptor rods and cones of the eye. Retinitis pigmentosa (RP), for example, is a retinal dystrophy characterized by pigment deposits on the peripheral retina, while the central retina is unaffected (1). It is an inherited disease caused by genetic abnormalities on several chromosomes (2). RP occurs in about 1 in 4000 childbirths and affects 1.5 million people worldwide (2).

The symptoms of RP grow more severe over a number of decades, but the rate of this progression varies among patients (1). RP has three primary stages.

The first is night blindness, in which the patient suffers from peripheral visual defects in dim light (1). This is because the photoreceptor rods responsible for scotopic vision, or low-light vision, have degraded. However, patients are usually not diagnosed with RP until the disease has progressed into the middle stage. During the middle stage, patients experience complete peripheral vision loss, which affects everyday tasks such as driving. Those with RP also become photophobic, or sensitive to white, diffuse light, making reading and other simple activities difficult (1). By the final stage of the disease, patients are no longer able to move autonomously due to severe peripheral vision loss (1). Similar to tunnel vision, patients at this stage only have vision around a single fixation point. If left untreated, this central visual field vanishes, and vision is lost entirely (2).

Another common form of photoreceptor loss is seen in age-related macular degeneration (AMD). It is the leading cause of blindness in the Western world, and affects approximately 700,000 people in the United States annually (3). Currently, 20 to 25 million people suffer from this disease globally, and in the next 30 to 40 years, this number is projected to triple (4). Similar to retinitis pigmentosa, experiments have shown that “genetic predisposition plays a major role in the aetiology of AMD” (5).

Usually, symptoms of AMD are not apparent until the patient is 50 years old. Aging reduces the efficiency of the retinal pigment epithelium in the eye. When this happens, the retina can no longer receive proper nourishment and accumulates waste material or drusen. This type of AMD is known as the “dry” type of AMD. The “wet” type of AMD features abnormal blood vessel growth.
through the Bruch’s membrane, which leads to dense scarring of the macular area. This type of AMD accounts for 90% of vision loss in elderly people (4).

Researchers have made several promising advances in delaying the onset of RP and AMD. These range from gene therapeutics to pharmacological treatment. However, these treatment options can only delay the death of photoreceptor cells, and once total blindness occurs they are no longer viable options. Scientists continue to search for a method to replace the function of photoreceptor cells in order to fully restore vision. The most promising approach to achieving this is the use of bioelectric retinal prostheses (3).

A New Hope

Bioelectric retinal prostheses are the result of merging progress from biomedical engineering with advancements in retinal surgery. This process began with the discovery that it was possible to induce vision by electrically stimulating the visual cortex. While under local anesthesia, the cortical surface of a blind patient was electrically stimulated, and the patient reported a spot of light in his visual field. These spots of light are termed phosphenes, and they are the precursor to restored vision. Groups experimented with different methods of inducing phosphenes in blind humans, and in the 1970’s it became clear that phosphenes could be elicited “with a contact lens as a stimulating electrode” (3). This method would stimulate the inner retinal cells, whose function had been lost due to degenerative ocular diseases such as RP and AMD. Because of the prevalence of these diseases, retinal stimulation has been extensively researched (3).

A group of surgeons headed by Dr. Humayun, professor of ophthalmology and biomedical engineering at the University of Southern California and Second Sight were among the first to develop a retinal prosthetic device in 2002. This device consists of an external unit and an implanted unit. The external unit is a pair of glasses with a small camera attached to it. It is connected to a belt-worn visual processing unit (VPU). The VPU encodes visual information captured by the small camera and then transfers electrical stimulation commands to the implanted unit wirelessly using an external antenna. The implanted unit consists of an extracocular component (the electronic case) and an intraocular component (the electrode array). The electronic case is surgically attached to the temporal area of the skull, and conducts electrical current across the eye wall to the electrode array on the retinal surface. The electrode array is a square four-by-four layout of electrodes. Each electrode is 520 micrometers in diameter and set 200 micrometers away from an adjacent electrode (6).

Surgical implantation of the device began two weeks before the clinical trial (6).

The subject for the clinical trial was a 74 year-old male who suffered from RP. He initially had absolutely no light perception in his right eye and severely limited light perception in his left eye. For computer-generated tests, the subject was asked to report the position of an electrode as it was activated, and he was able to correctly indicate the position of the electrode and distinguish the difference between two electrodes (6). For several tests involving a small camera, the subject was able to successfully detect ambient light and the direction of moving objects. In a dark room, he could locate a flashlight carried by a person 2

Figure 2: The fundus of the interior surface of the eye for a normal patient (left) lacks the pigment deposits seen in the fundus of the patient with mid stage retinitis pigmentosa (right).
meters away, and in a lighted room, he was able to locate a dark object (6). Although this was far from fully restored vision, it was considered a major breakthrough. In an interview, Dr. Humayun reflected, “This is like the Wright Brothers. This is the first time we’ve been able to fly. It took a lot of work to get to this point, but this time, when we took off, we flew” (7).

**Argus II**

Clinical testing of the device Argus II revealed the possibility of creating clearer images by using more electrodes. Second Sight Medical Products used Dr. Humayun’s research to develop a similar retinal prosthesis named Argus II that utilizes 60 microelectrodes rather than the initial 16. Patients with Argus II had impressive results in clinical studies. These patients showed an improvement of 93% in a spatial-motor test that had them press spots on a touch screen in response to white stimuli (8). Furthermore, when given 60 seconds, most patients could identify individual letters, and a select few were able to read short words (9). Argus II received FDA approval in February 2013, so it is available for any patient suffering from RP rather than solely for use in clinical trials (10).

**Conclusion**

Electrically stimulating photoreceptor rods of patients with degenerative ocular diseases partially restores their vision. Researchers have made outstanding progress in retinal prostheses over the past decade, and they continue to be the most promising approach to vision restoration. Although total vision restoration is still out of reach, a few of the terminally blind now have a glimpse of what is to come. While it is still blurry for the moment, progress indicates that this image will clear with time.

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**References**


“This is like the Wright Brothers. This is the first time we’ve been able to fly. It took a lot of work to get to this point, but this time, when we took off, we flew.”

—Dr. Humayun

**Figure 3:** A sketch representation of the micro-electrode array.
**Introduction**

A recent Pew study showed that nearly forty percent of Americans under the age of 40 have at least one tattoo. However, traditional ink tattoos may soon be replaced by digital ones able to adapt and respond to cues from electronics or the environment. The process combines biology with electronics; possible applications include health care, wellness, and fitness (1). According to Professor Yonggang Huang of Northwestern University, the design of epidermal electronics blends materials science, digital circuits, and biology (2).

It has been predicted that epidermal electronics will be beneficial in health care, as they may help to gather information such as brain activity, heart rate, and respiration (1). For example, in neonatal care, premature babies often need to be monitored for appropriate breathing and heart rate. Instead of having to hardwire the infant to bulky machines, epidermal electronics will allow tattoo-like patches to be placed on the baby’s skin, performing the same monitoring functions as expensive and stationary equipment.

**Flexible and Bendable**

Two leaders in the field of epidermal electronics are John Rogers of the University of Illinois and the Motorola’s Advanced Technology and Projects Group led by Regina Dugan. Professor Rogers’ work focuses on developing flexible epidermal electronics which consist of stick-on, stretchable electronic circuits with elastic polymer backings that can be applied directly to the skin like a temporary tattoo (3, 4).

Rogers’ work combines research on small circuits and bendable materials to create circuits that can bend with the body (5). The small, flexible electronic circuits are thinner than a human hair and have similar bendable, stretchable, and compressible properties to those found in human skin (3). The circuits in epidermal electronic tattoos are embedded in an elastomer material, similar to the silicone that is used in the caulking and sealants used around windows and bathtubs. This elastomer has a restoring force and behavior similar to skin (6).

The wavy shape of the circuits allows them to bend, twist, scrunch, and stretch without compromising function (2). The design is able to withstand the effects of stretching, compressing, and twisting that frequently occur with an active body (7). Furthermore, the circuits are composed of layers of metals, polymers, and silicon that are only about 5 microns (0.000005 meters) thick. These integrated circuits include active and passive devices that form a “web” of electronics in an open mesh design.

The University of Illinois team developed a technique that is able to print circuits directly onto human flesh with a rubber stamp, which

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**Figure 1:** Tiny semiconductor circuits that stretch with the skin could be rubbed onto a person’s skin to monitor muscle activity, heart activity or even brain waves in real time without using bulky medical equipment, and they peel right off after use.
can then be covered with a spray-on bandage to form a protective coating. The ultrathin mesh electronics that comprise the circuit operate like a standard computer circuit board and include electrodes, sensors, and wireless communication systems, but are made up of a matrix of stretchy wires that can flex with the movement of the body. As a proof-of-concept, researchers at the University of Illinois made circuits with a wide array of components, including sensors, LEDs, transistors, radio frequency capacitors, and wireless antennas (1, 2, 3). The “tattoo” has a variety of measurement capabilities, including tracking strain in multiple directions to provide feedback as to how the user is moving, built-in electroencephalography (EEG) and electromyography (EMG) to measure electrical impulses in the skeletal structure or nerves, electrocardiography to measure heart activity, as well as temperature and light sensing.

Another adaptation of the traditional tattoo, recently patented by Nokia, involves the creation of a digital tattoo that takes advantage of ferromagnetic ink to respond to changes in electromagnetic fields (8). In order to accomplish this, standard tattoo ink is enriched with metallic compounds that are demagnetized by exposing the metal to high temperatures before the ink is embedded in a person’s skin. Once the tattoo has healed, the ink is re-magnetized with permanent magnets. While the procedure is very similar to traditional tattooing, the ink retains the ability to respond to electric and magnetic pulses, which can be adapted for a variety of purposes. One example is the ability of such a digital tattoo to respond to the magnetic pulses which can be emitted by a device such as a cellular phone. The magnetized ink in the digital tattoo might be adapted to respond to the ringing of a cell phone to result in a haptic sensation experienced by the body, such that the wearer would be able to experience the phone ringing through the tattoo (8).
Powering Epidermal Electronics

While the epidermal devices designed by Rogers and his team can draw power from induction or even from mini solar cells, other innovative techniques are also being designed and tested to serve as power sources for digital tattoos. For example, Joseph Wang and his team at UCSD have come up with a process involving harnessing electrons from lactate secreted in sweat, eliminating the need for any external equipment to drive the function of the tattoo (8, 9). By embedding enzymes that are able to process lactate into the tattoo, Wang was able to extract seventy microwatts per cm² of skin. However, this measure is somewhat misleading, since the actual device was only a few millimeters in size and therefore only generated about four microwatts of power. Powering epidermal electronics continues to be an active area of research, as scientists search for smaller and more self-contained means of driving digital tattoos.

Conclusion

As sensors become smaller and more powerful, they will be used more frequently and effectively to monitor the health of the human body, a task that is currently carried out with large, relatively immobile, expensive machines like ECGs. Epidermal electronics being tested now could provide doctors with a lightweight, incredibly small, portable alternative that is able to be applied directly to the surface of the body. Future uses of epidermal electronics could include the direct monitoring of the internal physiology of the human body, new and faster means of drug delivery, and the ability to regularly stimulate select muscles. Digital tattoos may also be adapted by the cosmetic industry to provide a means of altering tattoos after the initial ink injection process, or to provide additional functionality to tattoos that allows them to interact with other digital technologies.

References


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Insectivorous Bats Alter Foraging Decisions Based on Risk of Visual Predation

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Abstract

Animals may adjust foraging behavior to limit predation threat. Nocturnal foragers are under greater threat from visual predators when ambient light is relatively high. We tested whether insectivorous bats would adjust their behavior in response to cues of visual predators in combination with the addition of light. We recorded bat activity with an ultrasonic microphone under factorial combinations of light and simulated owl calls. Bat passes were less frequent in trials with simulated predator calls, and with the experimental addition of light without predator calls. These results indicate that an increase in risk of predation from auditory and abiotic cues, including exposure to light, may induce predator avoidance behavior. Over time, selective pressures can reward nuanced predator detection and avoidance behaviors, even at the cost of decreased energy intake from foraging.

Introduction

Optimal foraging theory predicts that animals should adopt foraging strategies that maximize their fitness via high resource capture (Pyke et al. 1977). However, risk of predation forces prey animals to balance foraging behaviors with predator detection and avoidance (Kavaliers and Choleris 2001). Bats, the only true mammalian fliers, have extremely high metabolic rates during active flight, 3-5 times higher than the maximum of equivalent-sized terrestrial mammals (Shen et al 2010). When foraging at night, insectivorous bats can fly continuously for up to seven hours, locating and capturing prey using high-frequency echolocation. This high energetic expenditure is fueled through rapid metabolism of ingested nutrients (Voigt et al. 2010).

As nocturnal foragers with visual predators, bats are more vulnerable to predation in higher ambient light (Lima and Dill 1990). Many insectivorous bats remain in their roosts during the high insect activity at dusk, presumably to avoid higher predation risk before full darkness (Rydell 1996). Similarly, some frugivorous bats avoid foraging during the full moon (Clarke 1983), and nocturnal rodents reduce foraging under experimentally manipulated high light conditions (Kotler 1984). On the other hand, light-induced reductions in foraging would needlessly limit resource capture if predators are absent.

We tested whether insectivorous bats in the montane forests of Costa Rica adjusted their foraging behavior in response to different combinations of light and simulated predator risk. Specifically, we evaluated effects of predator calls and manipulation of light on the frequency and duration of bat passes, which are both proxies for foraging activity. If bats are responsive to variable predation risks, they should reduce foraging in response to signals of predators, especially with increased light levels. Alternatively, if predation has been only a minor factor in bat fitness, or at least less important than meeting metabolic needs, bats may be nonresponsive to light or cues of predator presence.

Methods

We recorded bat activity at Cuericí Biological Station on the nights of 29-30 January, 2014. We used Avisoft Bioacoustics hardware and software (Avisoft Bioacoustics, Berlin, Germany) and an ultrasonic microphone to record bat calls between the hours of 18:30 and 21:00. In 40-minute periods, we conducted four ten-minute trials, randomly assigning treatments to time slots within this period. We manipulated the presence and absence of light and the presence and absence of predator calls to create four treatments. We turned on two lights over the lower Cuerici trout pond for light trials. To simulate predator calls, we played recordings of an Andean Pygmy Owl and a Striped Owl for 30 seconds every 90 seconds during the trial. Both the Andean Pygmy Owl and Striped Owl are found at high elevation sites in and around Cuerici and are known to prey on bats and other small mammals (Stiles and Skutch 1989).

We used SASLab Pro (Avisoft Bioacoustics, Berlin, Germany) to analyze recordings for bat passes. We recorded passes as independent if there was at least one second of silence between calls. We also randomly sampled ten bat passes from each trial to assess bat pass duration. We used bat passes and pass durations to capture changes in two potentially important measures of foraging behavior: the frequency with which a bat visits a foraging area (pass) and the time it spends in the area on each visit (pass duration).

Statistical Analysis

We performed a chi-square analysis to test for effects of light and predator calls on bat passes for each night. We also tested for effects of light, predator calls, period, and interactions of the three factors on bat passes for each night using a three way log-linear model (Quinn and Keough 2002). We performed an ANOVA to compare bat pass durations across treatments. We conducted all analyses in JMP 10 (SAS Institute, Cary, NC).

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Results

We recorded 222 bat passes in 73 sound files (Electronic supplementary materials). We observed three different bat call sonotypes (Fig. 1), including a *Myotis*-type call (Fig. 1a) and a *Phyllostomidae*-type call (Fig. 1c). We saw evidence of search calls, approach calls, and feeding buzzes (Fig. 2).

Frequency of bat passes was greater on the first night (N=178) than the second night (N = 44). On the first night, we found a significant difference in frequency of bat passes across treatment types (chi-square = 57.96, P < 0.0001, df = 1; Fig. 3). We observed more bat passes in the absence of predator calls, and number of bat passes varied with both period and the interaction between light and predator calls (Table 1). The most passes were observed during dark treatments without predator calls (Fig. 3).

No factor had a significant effect on bat passes on the second night, but when we combined data from both nights the effects of period (chi-square = 15.59, P < 0.0001 df = 1), predation (chi-square = 8.52, P = 0.004, df = 1), and interaction between light and predator calls (chi-square =19.54, P < 0.001, df = 1) remained significant.

Duration of calls ranged from 0.5 to 16.7 seconds (mean ± SE = 5.25 ± 3.6 sec), and neither predator calls, light, nor the interaction between light and predator calls had a significant effect on call duration (F1,36 < 1, P > 0.65 for all factors).

Discussion

We found that bats adjusted their foraging behavior in response to increased risk from visual predators. Bat passes were markedly less frequent in the presence of predator calls on the first night of our study (Table 1, Fig. 3), indicating that bats reduce foraging efforts when risk of predation is high. Light alone did not have a significant effect on bat passes on the first night, but the effect from the interaction of light and predator calls was significant (Table 1). In the absence of predator calls, bat passes were less frequent in the light, where risk of visual predation is greater (Fig.3). Thus, bats seemed to exhibit predator avoidance in response to both light levels and auditory cues. This supports the hypothesis that bats can adjust their behavior in nuanced ways according to details of predation threat (e.g., the combination of light with the call of a predator that hunts by sight).

<table>
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<th>Light</th>
<th>Predation*Light</th>
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Table 1: A log-linear model showed significant effects of time of night (period) and predation on the number of bat calls, as well as an interaction between predation and light.

Figure 1: Sonograms of three bat searching calls recorded over 20 milliseconds. a) Steep frequency-modulated sweep with drop off in frequency at tail end of call (*Myotis*-type) b) Relatively narrow band-width at end of call c) Relatively short call with three harmonic frequencies (*Phyllostomidae*-type).

Figure 2: Bat feeding buzz with steep frequency-modulated sweep, recorded over 260 milliseconds.

Figure 3: Bat passes on the first night were most frequent in the dark without predator calls. See Table 1 for corresponding analyses.
Neither light nor predator calls had an effect on bat passes on the second night, which could indicate bat habituation to our experimental stimuli. Further studies could investigate whether bats respond differentially to predation threat based on the relative abundance of predators in their environment, which would suggest the extent to which predator avoidance behavior in bats is innate versus learned.

Our findings provide evidence for a tradeoff between foraging and predator avoidance. Animals subject to predation pressure may commonly evolve avoidance behaviors in response to environmental conditions that indicate increased risk of predation. Despite a sacrifice in resource capture from foraging, long-term selective pressures can reward predator detection and avoidance.

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**References**

Prediction of Preeclampsia Through Plethysmogram Analysis

KELLY M. BRENNAN a, SHALOM DARMANJIAN b, SAVYASACHI SINGH c, NEIL EULIANO d AND TAMMY EULIANO c

Abstract

Preeclampsia is a hypertensive condition prevalent in 4% to 5% of all pregnancies and is a leading cause of maternal mortality. Physiologic changes that cause preeclampsia remain uncertain; however vascular changes are a hallmark. The indeterminate cause of preeclampsia coupled with the sole definitive cure of delivery make the prediction of preeclampsia a significant topic of investigation. The objective of this study was to determine whether features of the photoplethysmogram (PPG) differ between individuals destined to develop preeclampsia and those who are not. Obstetric patients were recruited to participate in recurring 20- to 30- min PPG/ECG recordings, starting prior to 24 weeks gestational age and continuing through delivery. Preeclampsia status was noted at delivery. Classification algorithms were developed based on a larger data set culled from delivering patients with known preeclampsia or normotension. This system had a sensitivity of 0.82, specificity of 0.82, and precision of 0.90 in diagnosing preeclampsia. The pre-delivery data was then tested using those algorithms. Data from the first trimester yielded a specificity of 0.53, sensitivity of 0.53, and positive predictive value (PPV) of 0.73; the second trimester yielded a specificity of 0.60, sensitivity of 0.60, and PPV of 0.79; and the third trimester yielded a specificity of 0.68, sensitivity of 0.81, and PPV of 0.91.

Introduction

Preeclampsia is a hypertensive condition prevalent in roughly 4% to 5% of all pregnancies and is one of the principal causes of maternal mortality (1). According to the American College of Obstetricians and Gynecologists (ACOG), diagnostic guidelines include hypertension and proteinuria at or beyond a woman’s 20th week of gestation (2). Preeclampsia is traditionally classified as mild or severe. Mild preeclampsia is characterized by new-onset hypertension with a minimum systolic blood pressure of 140 mmHg or a diastolic blood pressure of 90 mmHg, together with at least 0.3 g of proteinuria over a 24-h period. Severe preeclampsia is characterized by one or more of the following: a minimum systolic blood pressure of 160 mmHg or a diastolic blood pressure of 110 mmHg on two separate occasions separated by at least 6 h; and/or excretion of at least 5 g of protein in a 24-hour urine, or the presence of a number of complications such as pulmonary edema, oliguria, or neurological symptoms (3).

Preeclampsia in the Third World

Globally, preeclampsia accounts for 18 % of maternal deaths and up to 40 % of fetal mortality (4). The prevalence of preeclampsia in developing nations is roughly seven times greater than in developed regions in North America (2). In underserved nations, the increased fetal/maternal mortality stems from several factors: poor detection, management, and education for preeclampsia, delay in the decision to seek and availability of medical care, and health policies (2,5). Women in evolving regions are more likely to marry at younger ages and become pregnant earlier; these aspects play a significant role in a parturient who fails to recognize complications during pregnancy such as preeclampsia and seek proper medical attention. Furthermore, teen pregnancy is a risk factor for the disease. Reducing the complications of preeclampsia due to inadequate care would be facilitated by accurate prediction prior to the onset of symptoms. Because preeclamptic symptoms often present suddenly during the late second and early third trimesters of pregnancy, diagnostic tools and prediction methods for preeclampsia would benefit women, especially in developing nations (1,2,5-7). Supplementary diagnostic tools to predict preeclampsia may reduce medical costs (7). Existing prediction methods rely on costly technology and blood tests, which are impractical in remote locations (2,7).

Methods

Recruitment of Participants

With Institutional Review Board (IRB) approval, obstetric patients were recruited at UF Health Medical Plaza. Inclusion criteria included the following:

- Age 18-50
- Less than 24 weeks gestational age
- Non-hypertensive or with gestational hypertension
- Non-diabetic or with gestational diabetes
- No kidney disease
- No cardiac disease

We particularly sought women with preeclampsia in a prior pregnancy.

Data Collection Protocol

After written, informed consent, demographic information such as obstetric history, medications, height, and weight was recorded. Data collection included continuous 20- to 30-min ECG and PPG
recordings. The following information was recorded at each visit: gestational age, blood pressure, weight, new pregnancy complications, and new medications prescribed.

After delivery, records were reviewed to document preeclampsia according to the ACOG criteria. Where unclear, three obstetricians reviewed the records and diagnosis was based on the majority opinion.

**Feature Extraction**

All the PPG recordings were processed using sub-band-based spectral analysis to compute the feature measurements for the classifier. The PPG signal was subjected to the following processing steps. First the signal was pre-processed to remove artifacts such as baseline wander and power line interference. Time-frequency representation (spectrogram) using the Fourier transform (FFT) was then calculated in 10 second frames. Next, the spectrogram was divided into 30 sub-bands of equal width, spanning the frequency region of 0.01 Hz to 5 Hz. Next, the accumulated spectrogram magnitudes across all sub-bands were normalized so they summed to 1. Finally, for each frame, the 30 sub-bands were compressed into 8 features using a type II (unitary) Direct Cosine Transfer (DCT). For each frame, a feature vector of 8 DCT features and a 1st order differential of the features were used as the input to the classifier. The differential features provide information on rate of change of the DCT features.

**Classifier**

Two continuous density Hidden Markov Models (HMM) with three states were used as the classifier. The HMM is a statistical model that can learn temporal patterns in the data. In this application we were learning the temporal patterns in the frequency content of PPG data that correspond to preeclampsia patients. One HMM was trained for each class (preeclampsia or control). HMMs were trained using five iterations of the Baum-Welch algorithm. During testing, the new frame data was passed through the two HMMs and the Viterbi algorithm was used to determine the log-likelihood of each state path through the HMMs. The HMM with the highest probability state path was declared the winner and provided the label for the test patient.

**Simulation Steps**

The dataset was partitioned into train and test sets, followed by feature extraction of each set. HMMs were then trained and tested on the sets. Classification results were stored and the above steps repeated 100 times, aggregating the classification results.

**Receiver Operating Characteristic (ROC) Curve Steps**

The above simulation steps were repeated for different values of log-likelihood thresholds used in the test step. Scanning all possible thresholds generates the ROC shown in Figure 1. The ROC allows for the selection of the best model on a relative preference for sensitivity or specificity.

**Results**

Ninety-seven subjects were enrolled at the Medical Plaza and delivered before July 24, 2014. For this analysis we included only women without a history of chronic hypertension (n=79). Of these, 19 developed preeclampsia, and 30 remained normotensive. Fifteen were excluded from further analysis in this study because they developed gestational hypertension. The remaining subjects formed the test set.

The train set was derived from a detection experiment performed on Labor & Delivery (L&D) at UF Health. In this study laboring women, already known to be preeclamptic (n=34) or normotensive (n=40), underwent the same experimental protocol and formed both the train and test sets. Overall, the results gathered from the detection experiment included a specificity of 0.82, sensitivity of 0.82, and precision of 0.90.

The preeclampsics and controls from the detection experiment were then used in the train set for the prediction experiment.

The test set was formed by the antenatal data of subjects who remained normotensive through delivery, or became preeclamptic. The results gathered from the test set were then separated into first, second, and third trimesters: the first trimester yielded a specificity of 0.53, sensitivity of 0.53, and positive predictive value (PPV) of 0.73; the second trimester yielded a specificity of 0.60, sensitivity of 0.60, and PPV of 0.79; and the third trimester yielded a specificity of 0.68, sensitivity of 0.81, and PPV of 0.91.

Figure 2 shows the log-likelihood plot created using data obtained from the detection experiment collated from 100 simulations. Blue pluses represent control patients, and red crosses represent patients with preeclampsia. The x-axis represents the likelihood of the subject belonging to the “controls” model. Similarly, the y-axis represents the probability of the subject belonging to the “severe preeclampsics” model. Both axes represent the log-likelihood of the probabilities and since the likelihood lies in the interval [0, 1], the log-likelihood values are negative. The red- and blue-shaded region represents the labeling of preeclampsics and controls respectively. Hence, all red crosses lying in the red region (and blue pluses lying in the blue region) are the correct classifications.

**Discussion**

To lessen the severity of illness and reduce maternal-fetal morbidity and mortality, prediction of preeclampsia remains an encouraging research objective. Current work focuses on
plasma biochemical markers and Doppler ultrasonography of the uterine artery (1,3,4,6,8-10). Plasma biomarkers, which serve as quantifiable indicators of endothelial dysfunction (1), have been studied extensively. Of these markers, the ratio of soluble fms-like tyrosine kinase-1 (SFlt-1) to placental growth factor (PIGF) (4,8-10) carries the highest prediction rate for preeclampsia, at 89% (4). However, methods that combine multiple biomarkers with Doppler ultrasonography and clinical risk factors yield enhanced preeclampsia prediction rates (4). A second method that has been studied to predict preeclampsia prior to the onset of symptoms is Doppler ultrasonography of the uterine artery (1,3,6). This method, while not proven to be a reliable predictor of preeclampsia overall, has been shown to be more valuable in recognizing severe early onset preeclampsia (1,4,6).

Although biomarkers and Doppler ultrasonography of the uterine artery have been shown to assist with the prediction of preeclampsia, these methods are often unavailable in developing nations (2,5,7).

**Photoplethysmography and Heart Rate Variability in Preeclampsia**

Assessment of features, including maternal heart rate variability in ECG and pulse wave analysis from PPG, carries promise to predict preeclampsia at lower cost and through noninvasive routes. A preliminary study by Khalil et al. investigated the use of pulse wave analysis (PWA) of the radial artery as a novel technique to predict preeclampsia. Analysis of 210 normotensive patients with a singleton pregnancy found first-trimester PWA, obtained between 11+0 and 13+6 weeks of gestation, to play an important role in understanding the pathophysiology of preeclampsia and assisting with early screening (11). PWA has also been used to assess arterial stiffness, a common finding in preeclampsia. Studies by Kaihura et al. and Hausvater et al. have confirmed that established preeclampsia is associated with increased maternal arterial stiffness (12,13). Thus, detection of altered blood vessel dynamics may offer a method for the detection of preeclampsia.

Our early results are promising. With additional data more elaborate models will be applied utilizing a larger feature set from the ECG and PPG. This technology has the potential to identify preeclampsia prior to onset of symptoms, facilitating the direction of medical resources and reducing costs and maternal-fetal mortality.

**Acknowledgements**

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**Conflict of Interest**

Tammy Y. Euliano, M.D., is the study principal investigator and is married to Neil Euliano, Ph.D., the president of the supporting corporation, Convergent Engineering. Patents obtained and medical devices created may introduce monetary propositions.

**References**

Characterization of UV Absorbing Compounds and Sunscreens by HPLC and UV-Vis Spectroscopy

Abstract

Increased awareness of skin disease, particularly cancer, resulting from excessive sun exposure has encouraged further research of sunscreen technology. Formulations of commercially available sunscreens vary in both their composition and concentration of UV absorbing compounds and much concerning their formulation and performance remains proprietary. Reverse-phase HPLC analysis quantified the concentration of UV filters in commercial sunscreen. Using UV-Vis spectroscopy, baseline and photodecomposition spectrographic data for the UV filters and sunscreens were collected. The HPLC quantification of avobenzone and octisalate concentrations in a sunscreen yielded 3.29% and 4.97% (versus advertised values of 3.00% and 5.00%, respectively). Molar extinction coefficients at \( \lambda_{\text{max}} \) for avobenzone (\( \epsilon = 36,300 \)), octisalate (\( \epsilon = 7200 \)), and octocrylene (\( \epsilon = 9300 \)) were calculated. Both sunscreens and the control avobenzone lost their UVA absorbance capacity (>325 nm) post UV light irradiation. This study showed that the advertised concentrations of active ingredients are reported by mass percentages, and that the UV radiation-induced degradation of the photo-unstable avobenzone closely predicts that of the observed decrease in UVA absorbance of the two sunscreens.

Introduction:

Over-exposure to ultraviolet (UV) radiation in the UVA (315-400 nm) and UVB (280-315 nm) range of the electromagnetic spectrum can lead to skin damage, sunburn, and possibly skin cancer. The damaging effects of exposure to sunlight have thus encouraged the development of sunscreen products with various UV filters, which contain substituted aromatic and conjugated systems. The filters provide protection from harmful rays by absorbing intensely in the UVA-UVB region of the electromagnetic spectrum. Radiation below 280 nm (UVC) is not considered in the formulation of UV filters as it is filtered out by ozone in the atmosphere.\(^1\) Much of the current research on sunscreens development pertains to synthesizing novel substituted aromatic rings that absorb wavelengths longer than those of an unsubstituted ring alone.\(^2\) Some of the common structures in UV filters include salicylates, benzophenones, and cinnamates, triazones, benzoates.\(^3,4\)

Another class of common UV filters not investigated in this project is inorganic salts, primarily zinc oxide and titanium dioxide. These molecules have a slightly different mechanism of protecting against UV radiation from the filters described above, involving a combination of absorption and reflection of incoming radiation.\(^5\)

While there are currently many potential UV filters available for protection from the sun for use in the formulation of consumer products, there are limits on the availability of certain UV filters and they are regulated greatly by national laws.\(^6\) Some of the variance in policies and regulations can be explained by the constantly evolving knowledge of the potential harmful effects of sunscreen, such as estrogenic interference and free radical damage.\(^5,7\) In the United States, the more commonly used filters include avobenzone, octisalate, octocrylene, and homosalate (Table 1).\(^8\) Avobenzone is considered a broad-spectrum UVA/UVB absorber whereas the other four are classified as solely UVB absorbers.\(^6\)

In addition to “broad-spectrum” protection, another measure of the effectiveness of a sunscreen is the sun protection factor, SPF. SPF is defined as the ratio of the minimum erythematous dose of untreated skin to skin with sunscreen.\(^4\) Increasing the SPF is generally achieved by increasing the concentration of various filters and/or adding additional UV filters. Because no sunscreen provides 100% protection, SPF is misleading and largely a marketing tool and should be used purely for comparative purposes.\(^9\)

The high energy UV radiation has the potential to decompose the UV filters in sunscreen, vastly decreasing their protective abilities. The common sunscreen component avobenzone, for instance, readily decomposes in UV light.\(^10\) However, it is also known that combinations of various filters covering the UVA/UVB region can extend the duration of an individual filter’s protection.\(^11\) Much of this UV filter characterization is conducted \textit{in vitro}.

Two common instrumental techniques used for the quantification of the effects of UV radiation on the various active sunscreen components include High Performance Liquid Chromatography (HPLC) and Ultraviolet-Visible (UV-Vis) Spectroscopy. Both of these techniques are conducted in solution and several solvents are known to affect the absorbance spectrum of UV filters.\(^12\) Due to this, solvents must be selected carefully as to minimally interfere with the absorbance of the compounds to be studied.

HPLC is an effective technique to resolve complex mixtures into its various components. The principle of HPLC is similar to that of regular column chromatography; the mixture is separated based upon varying degrees of interaction with the mobile and stationary phases. This experiment used reverse phase HPLC (i.e. HPLC with a non-
polar stationary phase) due to the non-polar properties of the UV filters. There are many factors that influence the results of liquid chromatography including flow rate, sample size, column length and packing material, and mobile phase composition. Another viable alternative for characterization of organic mixtures is Gas Chromatography (GC). However, given the high molecular weights and relatively high boiling points (i.e. less volatile) of the target UV filters, GC would likely have produced unreliable results. The separation of some of the components in sunscreens has been achieved, however, by employing silyating agents to lower the components’ boiling points.14

In addition to HPLC, UV-Vis Spectroscopy is an integral component of investigating either individual molecules or mixtures (i.e. sunscreen) of UV filters. UV-Vis spectroscopy is ideal for this study given that all of the target molecules absorb strongly in the UVA and/or UVB region(s). For instance, the HPLC employed a UV detector to identify the individual compounds, both alone and in mixtures, based on the unique absorption spectra of each compound at a specific wavelength.

Additionally, UV-Vis Spectroscopy is an effective method of conducting photodegradation studies, as the breakdown of the UV filters is easily determined. The decomposition of the UV filters was examined through monitoring the decrease in absorbance of the UV filters versus time.15 The relationship between the amounts of incident light absorbed (A) and transmittance (T), the amount of light that passes through the sample unabsorbed was determined by the formula A = (log(T)).

This study has several objectives relevant to commercially available sunscreens and sunscreen components. First, several UV-Vis spectrographic methods for measuring the UV absorbance of various UV filters were created. Second, the given concentrations of the active ingredients in sunscreen were established and characterized. Lastly, the stability of common UV filters during exposure to strong UV radiation was investigated.

Methods:

Chemicals Used

The following three UV filters from Sigma-Aldrich were used: avobenzone (Cat. #: PHR 1073, 1 gram), octisalate (Cat. #: PHR 1081, 1 gram), and octocrylene (Cat. #: 1083, 1 gram). The solvents used for HPLC analysis are Fischer HPLC Grade acetonitrile and Fischer Optima acetic acid. The water was 18 Mohm High Purity grade. The isopropanol is USP/NF Grade by Pharmco-AAPER.

Stock Standard Preparation

A stock solution of avobenzone (2.0 mg/mL), octisalate (8.0 mg/mL), and octocrylene (8.0 mg/mL) was prepared. The appropriate amount of each compound was massed, placed into a 10 mL volumetric flask, and 5 mL of isopropanol were added. The solution was then sonicated for 10 minutes to fully dissolve the UV filter. Acetonitrile was added for a final volume of 10.0 mL of each stock solution. Solutions were covered with Parafilm, stored at room temperature, and placed in a drawer to avoid exposure to sunlight.

Sunscreen Sample Preparation

A stock solution for the two examined sunscreens, Coppertone Sport High Performance SPF 30 and CVS Pharmacy Sun Lotion SPF 30, (5.0 mg/mL) was made. A 0.50 g aliquot of sunscreen was placed into a 100 mL volumetric flask. Approximately 50-70 mL of isopropanol were added to the flask. The solution was sonicated until the sunscreen fully dissolved and isopropanol was added for a final volume of 100 mL. The solutions were capped with a glass stopper and stored at room temperature in a drawer.

UV-Vis Spectrometry Protocol

The Jasco V-630 Spectrophotometer was blanked with 3.0 mL of isopropanol in a 1 cm quartz cuvette. Finding effective and reproducible UV-Vis spectrographic methods in the literature for the various sunscreen components was difficult. Many of the standard curves were generated by “trial and error.” The target range for absorbance spectra were between 0.10 A and 2.5 A (A = absorbance units). Data was analyzed with Spectra Manager Version 2 made by Jasco.

Standard curves for UV Filters

A standard curve for avobenzone, octisalate, and octocrylene was created by measuring absorbance at the λ_{max} as a function of concentration. Each standard curve

<table>
<thead>
<tr>
<th>UV band absorbed</th>
<th>UV absorbance</th>
<th>MW (g/mol)</th>
<th>Water solubility (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVA</td>
<td>358</td>
<td>310</td>
<td>2.22</td>
</tr>
<tr>
<td>UVB</td>
<td>238,305</td>
<td>250</td>
<td>0.72</td>
</tr>
<tr>
<td>UVB</td>
<td>238,305</td>
<td>361</td>
<td>0.004</td>
</tr>
<tr>
<td>UVB</td>
<td>238,305</td>
<td>262</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Table 1: The structure and properties of four common UV filters in the United States
was made by injecting 5.0 μL, 10 μL, 20 μL, or 30 μL of the corresponding UV filter stock solution into 3 mL of isopropanol. The volume of acetonitrile from the stock UV filter solution was insignificant compared to the volume of isopropanol and thus assumed to have no effect on the absorbance spectra. The range of concentrations ranges are used to generate a calibration curve for UV filters are shown in Table 2.

**Sunscreen Spectroscopy and Photodegradation**

Basic absorption spectra of the sunscreen samples determined by injecting 100 μL of a stock solution (5.0 mg/mL) into 3.0 mL of isopropanol for a final concentration of 0.16 mg/mL. The photodegradation study was conducted by injecting 150 μL of sunscreen into 3.0 mL of isopropanol for a final concentration of 0.25 mg/mL. The samples were irradiated in quartz cuvettes using a 150-Watt Hitachi Xenon Lamp. A baseline absorbance spectrum of each sunscreen solution was taken prior to irradiation and then after 15, 30, 90, and 150 minutes of exposure to UV radiation irradiation. Further, photodegradation spectrum of avobenzone (0.013 mg/mL) and octisalate (0.080 mg/mL) were taken prior to irradiation and after 10, 20, 30, 40, and 90 minutes of exposure to UV radiation irradiation.

**High Performance Liquid Chromatography:**

The HPLC study of sunscreen was conducted by modifying a commercially available method developed by Perkin Elmer. The HPLC system consisted of the Waters Automated Gradient Controller, 486 Tunable Absorbance Detector set to 325 nm, and two 515 HPLC Pump. The stationary phase was the Supelco Ascentis C18 column (Catalogue #581308). A two-component isocratic mobile phase was used: 90% of HPLC grade acetonitrile and 10% of 1.25% acetic acid in water. The solvent was degassed with helium gas. Prior to running samples, baseline readings were taken for an hour.

An aliquot of 10 μL of sample was injected into a 5 μL injection loop for each run. The system flow rate was maintained at 0.6mL/minute at a pressure between 450-550 psi. Data analysis was conducted using the N2000 Chromatostation Version 3.30.

**Regression Analysis:**

Linear regression analysis for both the UV-Vis Spectroscopy and HPLC analysis was performed using the Microsoft Excel 2007 software.

**Results:**

Known concentrations of avobenzone and octisalate were plotted against their respective peak area, as determined by HPLC, to create the standard curves ([Avobenzone: 424047 x – 79, R² = 1.00], [octisalate: 19016 x – 81, R² = 0.999], where y = area under HPLC curve, x = concentration of UV filter in mg/mL). HPLC analysis of the CVS 30 SPF sun lotion (1 mg/mL) produced peak areas of avobenzone and octisalate to totaling 13871 and 866, respectively. Thus, the concentration of avobenzone and octisalate in the sunscreen were determined to be 3.29% and 4.97%, respectively by mass.

**Figure 1:** HPLC analysis of sunscreen composition and UV filter concentration. a) Calculated concentration of avobenzone and octisalate by HPLC analysis of 30 SPF CVS sun lotion as compared with the advertised concentrations (sunscreen was diluted 1:5 for an injection concentration of 1.0 mg/mL). b) Avobenzone standard curve concentrations at 0.0065, 0.013, 0.048, and 0.20 mg/mL (made from avobenzone standard stock solution of 2.0 mg/mL). c) Octisalate standard curve concentrations at 0.077, 0.38, 1.92, and 3.2 mg/mL (made from octisalate standard stock solution of 8.0 mg/mL). d) Sample chromatogram generated by HPLC analysis of 30 SPF CVS sun lotion (5.0 mg/mL).
Absorbance spectra of avobenzone, octisalate, and octocrylene were collected. Avobenzone absorbs strongly in the UVA region with some absorbance in the UVB and UVC regions, whereas octisalate and octocrylene both absorb most strongly in the UVB region (Figure 2). Additionally, standard curves were constructed to calculate the molar extinction coefficient of each of the three UV filters at their reported λ<sub>max</sub> within the UVA/UVB regions. The molar extinction coefficient, ε, is defined by the relationship in Equation 1:

\[ \text{Absorbance} = l \times c \times \varepsilon \]

The molar extinction coefficient was determined in this study by measuring the slope of the standard absorbance curves because the path length was 1.0 cm and the slope is equal to (ε x l), which equals ε. This study reports the molar extinction coefficients to be: ε<sub>avobenzone</sub> = 36275, ε<sub>octisalate</sub> = 7164, and ε<sub>octocrylene</sub> = 9291 (Figure 3).

The photodegradation of CVS 30 SPF and Coppertone 30 SPF sunscreens was examined by UV-Vis spectroscopy. The photodecomposition was quantified by measuring the absorbance of these sunscreens at the two major absorbance peaks of 305 nm, the major peak in the UV range for octisalate, octocrylene, and homosalate, and 358 nm, the λ of greatest absorbance for avobenzone. Note that because 305 nm is the λ<sub>max</sub> for all three UVB specific absorbers, characterization of the individual filter decomposition was impossible. Both sunscreens degraded in a relatively similar manner. From 0 – 30 minutes, both sunscreens degraded very slowly, but somewhere in the time range of 30 – 90 minutes of UV radiation irradiation, the rate of this process increased rapidly (Figure 4).

Because the most rapid decrease in sunscreen absorbance was in the UVA region, the degradation of avobenzone, the only active ingredient in the sunscreen to have significant absorbance in the UVA region, was examined. Initial decomposition of avobenzone (0 – 20 minutes) was slow. The rate of decay then rapidly increased after 20 minutes, and by 90 minutes, the absorbance of avobenzone was close to zero at 358 nm, indicating that almost all of the compound had been decomposed. The photodecomposition of another compound in sunscreen, octisalate was similarly studied. However, there barely a significant difference between the absorbance capacity of the octisalate before and after 90 minutes of intense UV light exposure (Figure 4).

**Discussion/Conclusion:**

Sunscreen is important due to increased awareness of the relationship between sun exposure and skin related illnesses. Thus, much research has been conducted to improve sunscreen technology. Despite increased research...
and knowledge of UV filters, much of the information regarding individual and novel UV filters is considered "proprietary," which can make access of their properties and performance in the literature difficult (as determined by literature searches, both in journals and patents). For instance, molar extinction coefficients in the literature are readily available for certain compounds while not reported for others. Additionally, direct comparison between these studies is difficult due to differences in experimental techniques (e.g. solvents).

The molar extinction coefficients for avobenzone, octisalate, and octocrylene in ethanol in the literature are 34,000, 12 4200, and 12,700, respectively, versus our reported values of 36,000, 7200, and 9300, respectively. Further study of the molar extinction coefficients of these compounds may explain and reduce the discrepancies between this study and the reported literature values. This study cannot report any spectrographic data for homosalate because the compound was not available.

Another piece of "proprietary" information is the details surrounding the formulation of the total sunscreen product. Companies must identify each ingredient in the sunscreen, listed in descending order of concentration, and must include the actual concentration of UV filters in sunscreen by percentage (%). Companies do not, however, specify whether the percentage of UV filters is reported as mass or volume. Previous studies analyzing the composition of sunscreen by HPLC have concluded that the listed concentration of the percentage of UV filters is reported as mass or volume. Previous studies analyzing the composition of sunscreen by HPLC have concluded that the listed concentration of the percentage of UV filters is reported as mass or volume. Previous studies analyzing the composition of sunscreen by HPLC have concluded that the listed concentration of the percentage of UV filters is reported as mass or volume. Previous studies analyzing the composition of sunscreen by HPLC have concluded that the listed concentration of the percentage of UV filters is reported as mass or volume. Previous studies analyzing the composition of sunscreen by HPLC have concluded that the listed concentration of the percentage of UV filters is reported as mass or volume.

Assuming that the concentrations of UV absorbing compounds in sunscreen are indeed mass percentages as previously reported, this study suggests that, based upon the analysis of avobenzone and octisalate in two commercially available sunscreens, the advertised label likely represents the true actual concentration of these compounds in the sunscreen product. Additional testing of the two remaining compounds, octocrylene and homosalate, was further complicated by clogging of the HPLC column and the lack of availability of homosalate.

Much of the attention around sunscreen focuses on its sun protection ability. There are various methods, both in vitro and in vivo, described in the literature to study sunscreen performance. Because of the non-feasibility of in vivo, this study was limited to various in vitro techniques.

One of the commonly cited spectrographic techniques involves placing a small volume of sunscreen between two quartz plates and measuring the absorbance of the thin layer using UV-Vis Spectroscopy (usually around 2 mg/cm²). This quartz plate spectroscopy is preferred because the quartz plate method is more representative of sunscreen behavior in vivo. While there is no data presented in this paper, initial attempts at reproducing the quartz plate method were unreliable and inconsistent due to high absorbances in the range of 3.0 A to greater than 7.0 A. These absorbance values are likely due to a combination of light absorbance and scattering due to a turbid sunscreen layer between the quartz plates. Thus a liquid phase spectrographic assay was used instead.

As expected, the two commercial sunscreen products decomposed upon irradiation by UV light in an isopropanol solvent. While there was significant degradation of UV filters absorbing in the UVB region, the most dramatic photodegradation occurred in the mid to upper UVA region. Based upon the liquid phase spectrographic data for homosalate and ouncesalate in two commercially available sunscreens, the advertised label likely represents the true actual concentration of these compounds in the sunscreen product. Additional testing of the two remaining compounds, octocrylene and homosalate, was further complicated by clogging of the HPLC column and the lack of availability of homosalate.

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time points.

Photodegradation studies of two individual UV filters, avobenzone and octisalate, were conducted. Avobenzone, as hypothesized, was almost entirely degraded after 90 minutes of intense UV radiation exposure. In contrast, octisalate maintained almost all of its absorption capacity in the UVB region. This result suggests that avobenzone decomposition in the sunscreens leads to the decreased absorption capacity in the UVA region. Additional studies are required to better characterize the observed decrease in absorption of sunscreen in the UVB region after UV radiation irradiation.

An unexpected result, though, of the avobenzone degradation study was the non-linear decay of avobenzone with a consistent absorbance peak between 250 and 275 nm, as previously reported. This study reports the avobenzone to decay in a logistical fashion and further work is needed to determine the cause of the discrepancies. One potential explanation could involve the purity of the compounds used, especially given that none of them were of the highest available purity (i.e. HPLC or analytical grade).

A possible mechanism for the decay of avobenzone may involve radical species. The linear, possibly first order, decomposition from 0 – 20 minutes may be the result of UV induced homolytic-like fragmentation of the avobenzone molecule, as previously observed, into radical species resembling derivatives of benzaldehyde and acetophenone. The curve might become exponential when the radical species reach a threshold concentration, initiating a chain reaction. The radical fragments might be predicted to absorb in the upper range of about 240 – 300 nm, which somewhat resembles that of the relatively stable and slight increasing peak on the absorbance spectra for the decomposition of avobenzone by UV light. An experiment to test the radical pathway hypothesis might involve repeating the photodecomposition study of avobenzone in the presence of a known radical quencher, such as vitamin C.

References


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