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Light and Truth: Measuring Unseen Harm in Individuals and Communities

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ABSTRACT

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While the fields of physics and international development may seem disparate, the insights gained from studying each one of them can improve understanding of the other. Here, I demonstrate that concept as applied to computational optics and historical memory. Thus, the purpose of this project is threefold: (1) to computationally model light transport through tissue, and use that model to inform choices about a physical system; (2) to determine the types of historical memory recommended in the final reports of truth commissions; and (3) to give evidence for the usefulness of human-centered design in both areas. To model light transport, I used a Monte Carlo simulation of light at 1602 nm in tissue. I found that properly focusing the beam of light in a tissue-spectrometer system resulted in a fractional increase of 8.044×10^{-1} in the arterial signal-to-shot-noise ratio, with a fractional error of 1.807×10^{-2}. To investigate truth commissions, I classified coded data from 15 of the national-level final reports studied by the Global Truth Commission Index according to types of historical memory, divided into 58 distinct variables. I found that the most commonly cited form of historical memory, building a monument, was recommended in the final reports of 10 of the commissions studied; 7 commissions recommended public sensitization/awareness programs; and 7 mentioned creating a holiday or a day of remembrance.

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I would first like to thank my advisor, Dr. Robert Davis, from whom I have learned so much. Thank you for allowing me to work in your lab and for supporting me through my undergraduate research. The skills you have taught me will bless me throughout my life.

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I'd also like to acknowledge my sweet husband, Aaron, who by now has learned more about truth commissions and non-invasive glucose monitoring than he ever expected. Your support has been invaluable.

Contents

Chapter 1

Introduction

Taking data is the way the human race attempts to comprehend the incomprehensible. Various challenges impact the way we live our lives, both on an individual scale and a societal scale, and most of these problems can't be solved using simple analytical methods; thus, we endeavor to approximate solutions whenever necessary. This approach necessitates large amounts of high-quality data.

Researchers need to be innovative as they approach solving these problems, whether the approach is numerical, philosophical, or somewhere in between. One method of innovation is interdisciplinary studies. For example, although the methodologies and desired results of social science and physical science research are traditionally very different, these approaches are sometimes paired together. In recent years, these combinations have become both more prevalent and more creative.

Here, I discuss the connections between biomedical spectroscopy and historical memory in truth commissions. The combination of these two disciplines yields insights that separate analyses would fail to uncover. Most notably, I show the usefulness of applying principles of human-centered design in both areas.

1.1   Human-Centered Design

Although my original research is not specifically about human-centered design (that is, I present no *new* contributions to the scholarship on this topic), it is of such importance to the eventual conclusions from my research that it merits its own section.

Human-centered design is a problem-solving approach that focuses on participatory action research at every stage of the design process. When applying human-centered design to a research project, investigators make frequent prototypes and test them on users, seeking feedback continuously as the project progresses. "Speaking broadly, the human-centered design movement addresses and contemplates the multitudinous facets of human life, considering how any and all of them can be impacted by the product's features" [1]. Projects that seek to provide goods or services to people can benefit from these principles.

While human-centered design can be a valuable tool, innovators must take caution to not become *too* caught up in meeting the present needs of customers. Some user preferences are fleeting; therefore, a product that takes some time to come to market or is intended to last for many years can suffer if designers place excessive focus on user desires. Thus, care must be taken by the researcher in distinguishing central principles from minutiae. When such care is taken, human-centered design increases the usefulness of final products.

1.2   Optical Spectroscopy

1.2.1   Background: Diabetes and Monitoring Glucose

In collaboration with Tula Health, the Brigham Young University spectroscopy research group led by Dr. Richard Vanfleet and Dr. Robert Davis is developing a wearable device, similar to a smartwatch, to measure blood sugar non-invasively. The device is being

developed to "non-invasively and continuously [measure] glucose, movement, heart rate, oxygen levels, blood pressure and water content" [2].

According to a 2018 statistical report from the US Center for Disease Control and Prevention, 34.2 million Americans suffer from diabetes [3]. Proper management of this disease involves frequent measurements of blood glucose. The traditional method for measuring blood glucose involves sticking the finger with a lancet and putting a drop of blood from the fingertip on a test strip; a glucometer measures the blood glucose level from the test strip. While this method produces accurate, fast results (the test takes ∼15 seconds to process), it only gives information about that particular moment in time, so it must be repeated frequently to give a clear picture of a person's blood glucose throughout the day. The invasive nature of this test causes pain and inconvenience [4].

Continuous glucose monitors are more convenient and give more data, but they are typically less accurate and much more expensive; they also need to be replaced or renewed frequently. One such example is the Dexcom G6.[1] Every seven days, users must use a needle to insert a sensor just under the skin; the sensor tracks blood glucose continuously and sends the information to a smartphone app. Although this model monitors blood glucose continuously, it is still invasive and requires frequent upkeep. Moreover, this and other continuous glucose monitors are expensive—prohibitively so in some cases. They have high up-front costs and high continuing costs because users must replace the sensors so frequently.

Another particularly pervasive issue in monitoring blood sugar is what recent scholars have termed the "knowing-doing gap" [5]. This refers to a disconnect between what an individual or industry knows to be the best practice and what they actually implement. The knowing-doing gap appears in the healthcare industry, particularly in chronic disease

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[1]See https://www.dexcom.com.

prevention and management. That is, even if someone with diabetes knows that they would be healthier if they measured their blood sugar more frequently, their own habits, biases, and inclinations may cause them to act in direct opposition to that knowledge. One proposed solution to the knowing-doing gap in management of chronic disease is to apply the principles of human-centered design, traditionally used in social science, to healthcare [6]. Further discussion of this concept is found in Chapter (3).

To summarize, there are three key elements of an effective glucose monitor that current systems lack: Effective systems must be (1) non-invasive, (2) continuous, and (3) have low ongoing costs. In response to this lack, the BYU-Tula research group seeks to develop a watch-style glucose monitor that can be worn continuously without replacement and without breaking the skin in any way. It incorporates a miniaturized spectrometer system to measure infrared transflectance from the radial artery. The measurement system consists of an infrared LED bank to illuminate the artery from the surface of the skin on the inner wrist and an InGaAs spectrometer placed against the skin near the radial artery. The spectrometer is sensitive to light in the range of 900-1700nm; the LEDs that provide illumination are chosen to span this range of wavelengths.

1.2.2 Scientific Question

Here, I seek to answer one primary question: At what position of LED bank and detector respective to the radial artery is **shot noise from the pulsatile arterial signal minimized**? Because of the non-planar geometry of wrist elements and the high degree of randomness associated with light propagation in tissue, this problem cannot be solved analytically. Instead, a computational simulation is necessary.

The Monte Carlo (MC) method is a computational strategy that uses repeated random sampling to achieve numerical results for problems that often don't have analytical solutions.

MC simulation is a useful technique for predicting the outcome of a system that is affected by random variables. Since optical scattering in biological tissue has a high degree of randomness, MC simulation is the industry standard for modeling light transport through tissue [7]. In this method, the user specifies a particular probability distribution, and the program models a large number of pseudo-random events that produce an overall outcome according to the required distribution [8]. In this case, the given distribution comes in the form of optical constants (absorption, scattering, and anisotropy) that describe how light is absorbed and scattered through the medium [9] (see Table (2.2)).

Monte Carlo modeling of light transport is an application of photonics: The program models one photon at a time and determines how that photon might travel through a medium with a given set of optical parameters. Each simulated photon experiences a pseudo-random walk. That is, while the path of the individual photon may appear random (and, indeed, its path is determined by a large number of random-variable calls within the code), when taken as an aggregate, the paths of all of the photons follow the aforementioned probability distribution. Thus, repetition—that is, a very large number of samples—is crucial to Monte Carlo methods [10]. This gives rise to the major disadvantage of using the Monte Carlo method, which is its long computation time.

The code I use to simulate the process of light transport through biological tissue is called mcxyz-tula. Mcxyz-tula is a modification of mcxyz.c, a Monte Carlo simulation written by Steven Jacques. Nick Morrill and Elliot Brown made these modifications to fit our purposes.

As explained by Steven Jacques, the author of mcxyz.c, "The program mcxyz.c is a computer simulation of the distribution of light within a complex tissue that consists of many different types of tissues, each with its own optical properties. The program uses the Monte Carlo method of sampling probabilities for the [step size] of photon movement

between scattering events and for the angles (θ, ψ) of photon scattering" [11].

1.3   Truth Commissions

I now move to my discussion of truth commissions. Truth commissions function as a post-conflict mechanism for mitigating harm to individuals and communities.

When governments transition violently, gross human rights violations often occur. However, these violations often go unreported or unprosecuted for various reasons, including unstable transitional governments, legal and/or judicial corruption, cultural taboo against victims giving testimony, and many more. The field of transitional justice has grown out of this need. According to the International Center for Transitional Justice, "Transitional justice refers to the ways countries emerging from periods of conflict and repression address large-scale or systematic human rights violations so numerous and so serious that the normal justice system will not be able to provide an adequate response" [12].

A truth commission (TC), also called a truth and reconciliation commission, is a non-governmental body established as a form of post-conflict transitional justice. Its purpose is to discover wrongs committed by state and non-state actors during a particular time frame and to offer recommendations for how to mitigate them. Truth commissions also seek to influence the political and judicial actions of those in power [13]. When a TC is completed, its commissioners write a final report (FR) that summarizes the findings and provides recommendations for post-conflict healing. Truth commissions take advantage of a proposed relationship between truth-telling and peacebuilding. Whether a truth commission is able to utilize that relationship in a productive way, however, depends largely on the structure of the commission and the quality and effective implementation of its recommended reparations programs [14, 15].

The Global Truth Commission Index (GTCI) is a project established at BYU by Professor Natalie Romeri-Lewis. The GTCI describes itself as "a non-profit research group rooted in the empirical study of truth commission efficacy for the purpose of enabling peace in post-conflict countries. We provide cross-national, comparative data at different stages of decision-making throughout the transitional justice period. This project aims to improve the technical design of truth commissions through increasing victim and perpetrator participation, quality and volume of truth gathered, final report dissemination, civil society accessibility, etc" [16]. The GTCI emerged out of a need for both breadth and depth in the study of truth commissions. Members of the GTCI code data from three stages of the truth commission process for national-level truth commissions and use that coded data to analyze individual TCs (as case studies) and cross-examine TCs from different countries (as comparative data) [17].[2]

This project branches off of the main GTCI code to provide further insight into the methods and effects of TC final reports. Here, I present an investigation into historical memory in truth commission final reports.

Historical memory is the way by which a group, community, or nation collectively remembers and identifies with a past event. For example, building a museum, holding a ritual purification ceremony, or incorporating details about certain historical events into school curriculum can function as historical memory acts. Collective, historical memorialization deals with the question of the "right to know" on the part of the citizens and the "duty to remember" as a responsibility of the state [18]. Specifically, historical memory acts attempt to help people heal from past atrocities while hopefully ensuring non-repetition of those atrocities in the future.

Memory acts have served as a form of transitional justice for many years, but especially

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[2]For a more in-depth discussion of the coding process, TC stages, and the goals of the GTCI, see Section (2.2).

since the Holocaust [19]. "Often deemed a 'soft' measure of TJ [transitional justice], memorialization can nevertheless play a key role in overcoming repressive pasts by providing symbolic reparations to victims of atrocities, promoting reconciliation through restoring public trust and solidifying a postcommunist society's commitment to a more democratic set of values" [20]. Truth commissions can be useful in prompting memorialization because, in theory, they circumvent the political polarization of state-inspired memory programs.

Caution, of course, must be taken in recommending historical memory acts in TC final reports. Amidst ongoing discussion among scholars about the best way to implement historical memory as a form of post-conflict healing, prominent voices in the field warn specifically against using Western memorial practices as a standard against which to hold truth commissions around the world. In particular, Lea David "argues that the human rights regime mandates normative standards that de-historicize and de-contextualize local knowledge...which not only disables different patterns of dealing with a traumatic past but also may strengthen societal divisions on the ground" [21]. The Freudian concept of confronting one's past to better heal from it doesn't work equally well for all cultures [19]. Thus, scholars assert that memory recommendations must be tailored to the culture in which they fit.

Truth commissions operate both as a form of historical memory and an impetus for the initiation of historical memory acts if and only if they are designed, implemented, and reported on in specific ways. The purpose of my investigation was to **determine if and how TCs address historical memory, both implicitly and explicitly**. Drawing from the mandates and from recommendations within 15 final reports of national-level truth commissions, I explore the extent to which governments in transition prioritize collective, historical memory. Moreover, I pinpoint which physical, educational, and social historical memory acts post-conflict countries favor. In doing so, I demonstrate instances of both

innovation and standardization in the historical memory recommendations found in truth commission final reports.

Chapter 2

Methodology

This section encompasses the methodologies of both my computational optics investigation and my historical memory research.

For my research in biomedical optics, I used a simulation of light transport through tissue to determine the location and orientation of the LED bank and the collimator-spectrometer system that optimize signal at the spectrometer. To "optimize" the signal, I maximized the signal-to-shot-noise ratio of light that travels from the LED bank through the radial artery and reaches the detector [22].

To study historical memory in truth commissions, I first selected 58 variables across 7 distinct categories related to collective memorialization. Then, I sorted previously coded data from 15 truth commission final reports to determine if and how commissioners address historical memory.

In an effort to maintain specificity and avoid reader confusion, the methodologies for these two projects are discussed entirely independently.

2.1   Monte Carlo Simulation

2.1.1   Definitions

Modeling a single photon by Monte Carlo methods takes a significant amount of computational time. The number of photons in a physical experiment is far too large to computationally model.[1] The use of **photon packets** is a strategy implemented in mcxyz.c to represent a larger number of photons without explicitly calculating the path for each individual photon. Thus, it increases the number of represented photons without increasing the computation time. Each photon packet is a proxy for some large number of photons that took the same scattered path through the tissue. Photon packets are only used in simulated light transport; they don't have a clear physical equivalent.

The energy of a photon packet is given by its **weight**, which decreases as light is absorbed along the path. The simulation launches each photon packet with a weight, or energy, of 1. As the photon packet travels through an absorbing medium, its energy decreases in proportion to the distance traveled; the rate at which its energy decreases is determined by μa, the coefficient of absorption for the medium through which the light is traveling. When the weight of a photon packet reaches a certain minimum threshold, it is considered "dead" and no longer propagates.

Computation is done via Amazon Elastic Compute Cloud (EC2), which is a part of Amazon Web Services (AWS). EC2 allows its users to rent virtual machines known as **instances** for temporary, flexible use. This allows multiple copies of the mcxyz-tula simulation to run simultaneously, vastly decreasing computation time.

Each instance controls up to 70 **workers** (simultaneous processors that each run the code in its entirety)—again, a strategy to minimize computation time. Each worker represents

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[1]With our simulation, it would take days of computing time.

some set number of photon packets (in this case, 8 million photon packets per worker), propagated through the medium one at a time.

The mcxyz-tula simulation is set up to run multiple **experiments** on each worker. Each experiment has a particular set of parameters and represents a unique physical system.

2.1.2   Assumptions and Simplifications

Various assumptions and simplifications are necessary to analyze the system using Monte Carlo methods. Here, the term "assumptions" refers to experimental parameters that are presumed to be true. "Simplifications" in this context are known to be untrue, but expected to have little to no bearing on the ultimate results.

Assumptions

Critical to the validity of this experiment, and readily proven analytically, is the assumption of a steady-state light distribution. That is, light travels fast enough with respect to pulse that we can optically compare the steady-state diastolic directly with the steady-state systolic [22]. We do not need to account for the rate at which light travels through the tissue.

Name	Size (mm)
Systolic artery diameter	2.7
Diastolic artery diameter	2.5
Artery depth	3.25

Table 2.1 "Standard" values for physical configuration in simulation.

Simplifications

The physical system modeled by the simulation has a few specific parameters that describe relative locations and sizes of the various elements. For simplicity and repeatability, the simulation uses standard values for artery diameter and depth, shown in Table (2.1). These values are taken from established research and represent an "average" human wrist. Of course, there is great variation in these parameters among people of various shapes and sizes; thus, without repeating the simulation for different values, these results may not be generalizable to persons with a different physical configuration.

A cross section of a wrist is shown in Fig. (2.1). The computational setup, however, neglects large interferers such as tendons, the radial vein, and bones (see Fig. (2.2)). The radial artery is modeled as a perfect cylinder. In order to be compatible with the chosen simulation methods, the modeled medium is planar: The surface of the skin is flat, and all internal non-blood tissue is layered parallel to the skin surface. The simulated configuration of surrounding tissue does not change with pulse—that is, the skin does not "bulge out" when the artery is at its largest diameter.
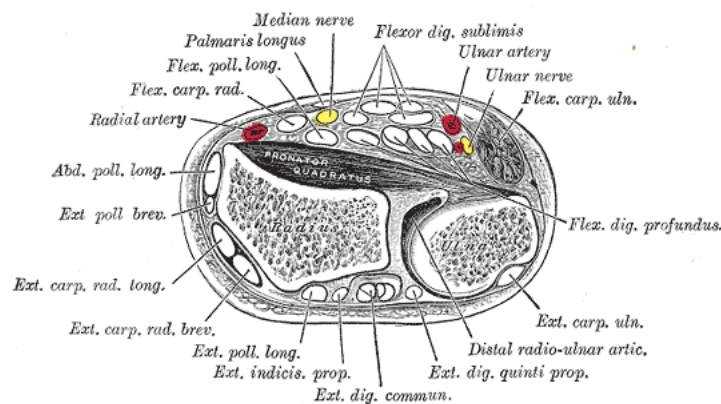

Figure 2.1 Cross section of the wrist. Note the radial artery, highlighted in red.

The simulation adopts a semi-infinite scattering medium. The medium stretches far

enough in every direction (except beyond the surface of the skin into air) that most photon packets don't reach the boundaries. Photon packets that reach a boundary, including the surface of the skin, are considered "dead" and cease to propagate. Reflection at internal boundaries (e.g. arterial wall) is not considered. The simulation also neglects reflection at the surface of the skin, including the LED-tissue interface and the tissue-detector interface. Light is input at a wavelength of 1602nm; because we assume insignificant fluorescence, the simulation neither accounts for nor considers a change in wavelength as the photon packets travel through tissue.

In this particular set of experiments, all of the modeled non-blood tissue has the optical properties of human dermis. The reason for this simplification is that the experimental measurements of optical constants for skin tissue include the outer two millimeters of tissue, which are composed of skin and adipose layers. This approach produces average scattering properties for tissue (called "standard tissue") rather than separate optical constants for skin and adipose layers, which simplifies the complex structure of tissue for modeling purposes [9].

This model utilizes several notable simplifications about the optical properties of biological tissue. One such simplification is to treat the arterial wall as though it has the same optical properties as blood. Physically, this isn't necessarily true, but it helps reduce the model to essentials. We further assume that the optical properties of cutaneous and subcutaneous tissue do not change with pulse. We assume that the optical properties of the blood do not change with pulse; that is, neither the speed at which the blood travels through the artery nor the pressure of the blood inside the artery (and, therefore, the pressure of the arterial wall on the surrounding tissue) affects the optical properties of the blood or the tissue.

2.1.3   Physical and Computational Design

Physical Configuration

The measurement system, including the infrared LED bank and the spectrometer, is placed directly on the surface of the skin of the inner wrist. The LED bank and the spectrometer are held a fixed distance apart; the point on the skin closest to the radial artery is between the LED bank and the spectrometer. The locations of the LED bank and the spectrometer, their distance from each other, and their respective orientations are variable in the simulation; greater discussion of these parameters is found in Section (2.1.3).

The physical configuration of the wrist is shown in Fig. (2.1), including arteries, bones, tendons, and skin. The depth and diameter of the "standard" radial artery are given in Table (2.1).

Simulated Configuration

The simulated setup that best resembles the physical arrangement of spectrometer, artery, and LED bank (though highly simplified) is the geometry shown in Figure (2.2). In this configuration, the simulated spectrometer receives signal at the surface of the skin, just as a physical spectrometer would. The simulation is three-dimensional; for simplicity, a cross section is shown here. Light, simulated as photon packets, is emitted from the LED bank.[2] Photon packets are then scattered through the medium. If a photon packet makes it back to the spectrometer, it is considered "detected."

Using this geometry, the mcxyz-tula model can simulate the actual physical signal that would result from an LED-spectrometer system placed near the radial artery. Quality of the signal is measured as a ratio of pulsatile arterial signal to shot noise. Arterial signal is a measurement of detected photonic energy, simulated as the sum of the weights of all photon

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[2]Emitted light can be collimated, isotropic, or focused.
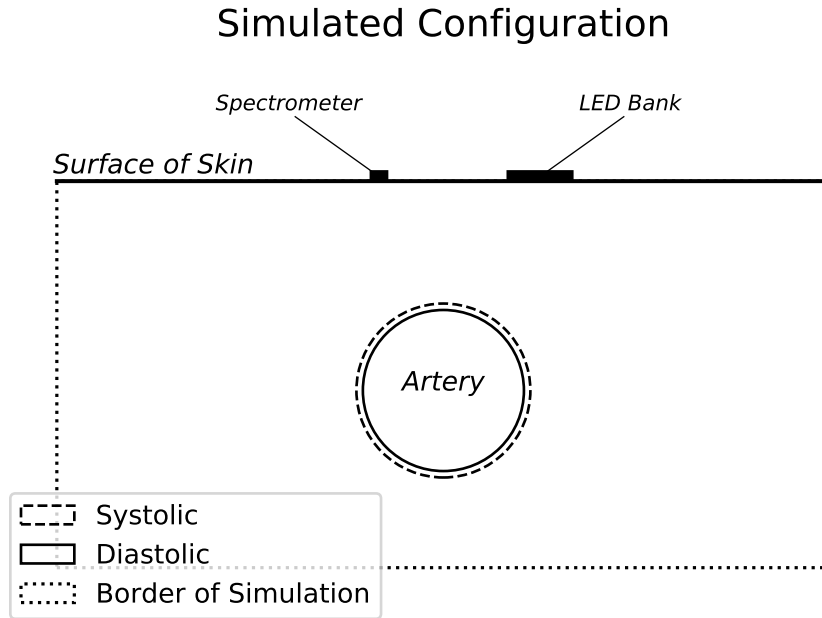
Simulated Configuration

Figure 2.2 Cross section of the simulated tissue and LED–spectrometer system, including the radial artery. "Systolic" simulations are performed with the artery at a diameter of 2.7 mm; "diastolic" corresponds to an arterial diameter of 2.5 mm. The $+x$ direction is to the right; the $+z$ direction is down.

packets that pass through the artery AND reach the spectrometer. Pulsatile arterial signal is the change in arterial signal between systolic and diastolic arterial states. Total detected weight is a sum of the weights of all photons that reach the detector, including those that pass through the artery and those that do not. This ratio can be expressed as follows:

$$\frac{|A_{sys} - A_{dia}|}{\sqrt{\frac{1}{2}(Total_{sys} + Total_{dia})}} \tag{2.1}$$

where A_{sys} and A_{dia} are the arterial signals for the systolic artery condition and the diastolic artery condition, respectively. Similarly, $Total_{sys}$ and $Total_{dia}$ represent the total number of photons that reach the detector for the two arterial conditions.

In order for the results of this simulation to be statistically viable for measuring change

in pulsatile signal based on change in glucose, the simulation would require a prohibitively large number of simulated photon packets. For that reason, I optimized the pulsatile arterial signal rather than the change in pulse based on a change in glucose, assuming that as the *arterial* portion of the pulse is modulated more significantly, the change in signal due to change in glucose also increases. Moreover, I tested the relationship between arterial signal and pulsatile arterial signal at multiple locations of source and detector. From this, I determined that at all locations relevant to this experiment, non-pulse-modulated arterial signal is proportional to pulsatile arterial signal. Their relative shot noise levels follow the same pattern. For that reason, I simplified the noise analysis described in Eq. (2.1) to the following:

$$\frac{A}{\sqrt{Total}} \tag{2.2}$$

This allowed me to minimize the computation time necessary to determine the optimal system geometry.

Simulation Parameters

This system is restricted by the degree of collimation of the spectrometer. In order to achieve the necessary spectral resolution to distinguish glucose peaks, the maximum allowable angle range of the collimator is $\pm 30°$.[3] This functions as the initial constraint on the system.

The artery modeled in the experiments simulated here is in its systolic state, which means that its diameter is 2.7 mm. I test detector positions at 0.5 mm intervals from 0.0 mm to 3.0 mm, where the position is measured as a distance in *x* from the projection of the radial artery on the surface of the skin. The source is tested at three different locations: 1.0

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[3]This particular collimator functions by "throwing away" any light that is incident on its face at an angle greater than the "allowable angle range." That is, any light incident on the collimator at an angle of greater than 30° from the normal is absorbed by the collimator and never reaches the spectrometer. See Section (3.2) for a more in-depth discussion of this parameter.

mm, 1.5 mm, and 2.0 mm, where the distance is measured from the arterial projection on the skin. The source and the detector are on opposite sides of the radial artery, as shown in Fig. (2.2). I simulate eight different focal points for the input light (including collimated light and isotropic light—infinite focal length and zero focal length, respectively).

Tissue Type	μ_a	μ_s	g
Standard tissue	0.20	15	0.90
Blood	0.69	29.43	0.9492

Table 2.2 Values of the optical absorption coefficient μ_a, optical scattering coefficient μ_s, and anisotropy factor g for selected biological tissues at 1602 nm [9].

Light is simulated at 1602 nm. The properties of blood and "standard tissue" at this wavelength are given in Table (2.2) The number of photon packets simulated for each experiment is 500000. Each experiment runs on 64 workers. Only one instance is used.

2.2 Coding Historical Memory

The purpose of the Global Truth Commission Index (GTCI) is to categorize and code data from national truth commissions. Coding, in this sense, involves gathering data from various sources and assigning it to positions within a table. The GTCI examines 350 variables that span the three stages of truth commissions: (1) design phase, (2) operational phase, and (3) final report phase [17]. The design and operational phases are not discussed in this document; the final report phase is the only portion relevant to the methodologies and results given here.

To create the final report dataset, members of the GTCI read national-level final reports and extract quotations that relate to the variables in the final report table. Coding that

quotation means putting (i.e. copying and pasting) the entire relevant quotation into the table at the appropriate location (that is, in the position corresponding to the correct variable). If a quotation relates to multiple variables, it is coded for all of them.

Drawing from recommendations within final reports of national-level truth commissions categorized by the GTCI, I explored the extent to which governments in transition prioritize collective, historical memory. Moreover, I pinpointed which physical, educational, and social historical memory acts post-conflict countries favor.

I took coded data from 15 of the FRs studied by the GTCI and further classified it according to types of historical memory, divided into 58 distinct variables in seven categories. That is, I took final report quotations already coded by the GTCI as "Recommendations and Reparations" and discarded the recommendations that didn't relate to historical memory, keeping historical memory data and assigning it to new variables. Determination of whether a memory-related quotation merited being coded as historical memory was dependent on three questions:

1. Is it for a group?

2. Is it forward-pointing?

3. Is it a recommendation?

If the answer to all of these questions was yes, that quotation was coded.

Some elements of historical memory are physical/tangible. For example, events and physical memorials contribute to this part of historical memory. Other elements are not tangible; instead, they relate to the actual memories held by a group or individual. For example, education is not tangible, but that is the mechanism by which the conflict and peace actually enter into the minds and memory of individuals and groups.

I coded only mentions of collective memory, which means that although individual reparations may contribute to memorialization for an individual or family, only reparations directed towards groups or the general public are included in my definition. Thus, in this definition of memory, the Final Report itself is considered to be memory if and to the extent that it is used as a tool for education and awareness.

My analysis takes place at the level of a country rather than an individual. Since most FRs make no effort to give information about every individual in the country, but rather offer an aggregate view of the country as a whole, this approach fits the data.

The 15 country-level final reports examined here are Ghana, Liberia, Morocco, Sierra Leone, Argentina, Burundi, Chad, DRC, El Salvador, Guatemala, Indonesia, Indonesia/East Timor 2004, Sri Lanka, Timor-Leste, and Togo.

I determined the variables to be used by coding each of five sample final reports two times. The FRs used as samples for determining variables were Ghana, Liberia, Morocco, Sierra Leone, and Argentina. I added variables fluidly as I coded those five countries the first time, making sure to keep all five up to date with any new variables. The second time I coded them, I did not add new variables; the purpose of the second coding was to ensure that no data points were missed as new variables were added in the first coding. After that, I only added a new variable if it was very clearly unique, and thus would not corrupt earlier data.

I followed some general principles in adding data points to the coded variables. I coded everything that explicitly related to memory, memorializing, collective memory, etc.

I did not code the quotations that related to burial/exhumations unless they were "forward-pointing" reparations (that is, some suggested way to remember those who died, not just offering peace, consolation, or information to families). I didn't include psychological or personal healing or community rehabilitation, reconciliation, or healing because they are not forward-pointing. I didn't code community building recommendations because although

they are forward-pointing, they do not relate to memory. I did not include general statements about memory or indications of past memory-building actions, only recommendations that the commission proposed going forward. I did not include anything about the search for the disappeared and/or reuniting families. I didn't code methods to combat social stigma, legislation/legal changes (unless they specifically pinpointed memory), or recommendations about death certificates.

Chapter 3

Conclusions

3.1   TC Innovation and Standardization

The balance between innovation and standardization in truth commission recommendations and reparations has been widely debated among scholars. A TC is "standardized" to the extent that it follows (and, hopefully, meets) guidelines established by some larger governing body. For example, the United Nations has published many reports that encourage specific actions by commissions and commissioners; these can be used as an example of standardization. Standardization also encompasses the degree to which a truth commission mimics previous commissions. "Innovation," in contrast, refers to measures that a particular TC comes up with independently of outside (meaning out-of-country) sources. With the idea of innovation comes the implication of cooperation with civil society groups and local leaders, including using local culture and customs to determine TC methodology and reporting.

There is some merit to each approach. On the one hand, standardizing requirements for TCs allows international governing bodies to influence the transitional justice process,
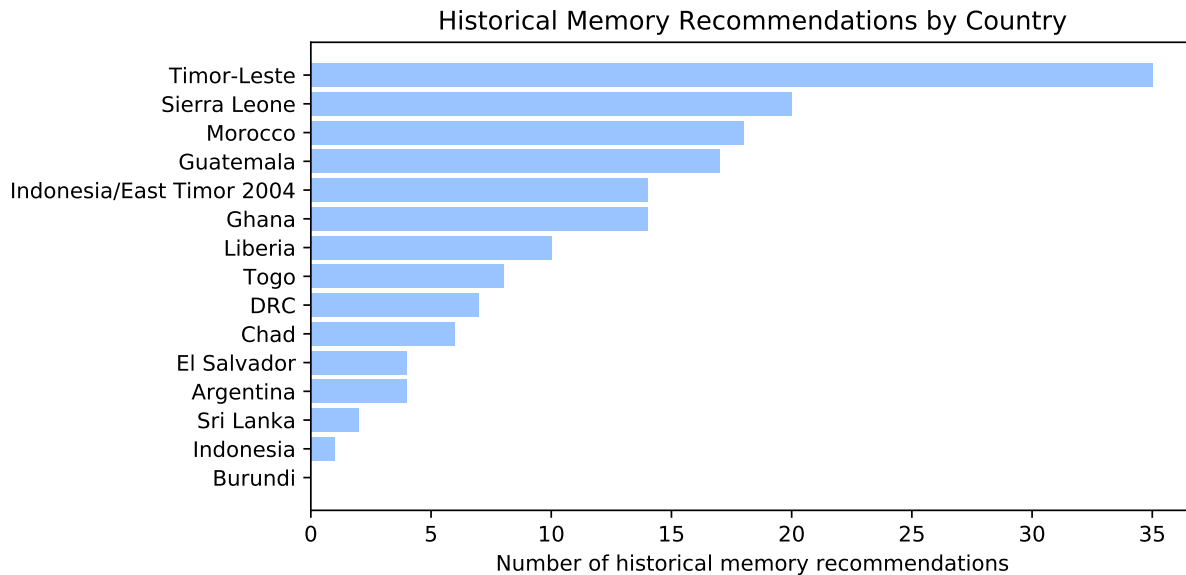
Historical Memory Recommendations by Country

Figure 3.1 These are values from coded data. This demonstrates the number of *unique* historical memory types recommended in each country-level final report.

ensuring that particular actions are carried out, including prosecution of certain perpetrators and reparations given to certain victim groups. Moreover, standardization helps to improve the efficiency of the commission by allowing present and future commissioners to build on the work of those past. On the other hand, creating an innovative, country-specific approach for each TC is often more effective in long-run implementation because local people tend to accept these measures more readily.

Results from my study of historical memory in truth commission final reports show that many FRs do not meet United Nations **standards** for memory-related reparations after gross human rights violations. Those that do, in many cases, also show evidence of **innovation**.

The countries whose final reports recommended the most distinct forms of collective historical memory were Timor-Leste, with 35 types mentioned; Sierra Leone, with 20; and Morocco, with 18. Values for other countries are shown in Fig. (3.1). The most commonly cited form of historical memory, building a monument, was recommended in

the final reports of 10 of the commissions studied; 7 commissions recommended public sensitization/awareness programs to educate about the conflict; and 7 mentioned creating a holiday or a day of remembrance.

Many final report recommendations sections address compensation, which refers to repayment (usually financial) for losses incurred during a period of gross human rights violations. This especially applies to families who have lost breadwinners. Another significant portion of typical reparation programs consists of guarantees of non-repetition. Historical memory, in contrast, is not emphasized in the recommendations section of every final report; there is a great deal of disparity between various countries' prioritization of collective, historical memory.

In 2005, the United Nations General Assembly approved and subsequently published a document entitled *Basic Principles and Guidelines on the Right to a Remedy and Reparation for Victims of Gross Violations of International Human Rights Law and Serious Violations of International Humanitarian Law*. It provides non-binding guidelines for the obligations of member states to assist victims of gross human rights violations. Two of the 27 recommendations given in this document directly address historical memory. The recommendation of "satisfaction" calls for "commemorations and tributes to the victims" and "[inclusion] of an accurate account of the violations that occurred...in educational material at all levels" [23]. The section on "guarantees of non-repetition," while mostly irrelevant to the topic at hand in this document, does include the call to provide "human rights and international humanitarian law education to all sectors of society and training for law enforcement officials as well as military and security forces" [23].

The United Nations' *Basic Principles and Guidelines* is not the only document wherein the United Nations has recommended that historical memory be prioritized in post-conflict situations. The UN has also recommended, as early as 1996, "commemorative ceremonies,

naming of public thoroughfares, monuments, etc.; periodic tribute to the victims; [and] acknowledgement in history textbooks and human rights training manuals of a faithful account of exceptionally serious violations" in response to gross human rights violations [24]. Thus, historical memory is an important part of truth commission recommendations and reparations.

Although *Basic Principles and Guidelines* is a useful starting point for historical memory recommendations, it is by no means exhaustive. In fact, of the 58 variables in my dataset, only 27 can be considered to fall under the broad categories listed in the UN guidelines. This shows the value of innovation. For example, it is unsurprising that building a monument was the most common form of historical memory recommendation among the final reports examined. There are numerous precedents throughout the world of monuments and memorials being built to commemorate tragic events. That so many final reports mentioned building a monument is a clear example of the perceived usefulness of historical memory recommendations as well as the standardization of certain ideas about what historical memory looks like in practice.

Several very innovative recommendations were put forward in the final reports examined here. Liberia's Truth and Reconciliation Commission recommended that a child-friendly version of the final report be written, published, and disseminated so that children could be educated about the conflict in an age-appropriate way. The FR from Timor-Leste's TC includes the recommendation that sports programs for youth be established in honor of victims. Some FRs recommended that certain records that glorified the conflict be destroyed; others advocated for the suppression of the commemoration of specific divisive events. Other examples of innovation in FRs include recommendations for art, literature, music, public parks, and more to be produced in commemoration of conflict.

The primary value of the standardization approach in this context is that it allows

commissions to build off of one another. In that way, the work of one TC does not only benefit the country it is for, but also any future commissions that draw from it.

There is, of course, a danger of becoming too prescriptive: Every country is different, and the memory acts that work well for one country—or even one community—could be disastrous for another. As stated in the final report of the Liberian Truth and Reconciliation Commission (TRC), "The TRC determined that religion and traditional culture, principles and values weigh heavily on the conscience of the Liberian people. As such a truly integrated reconciliation process must engage these institutions for sustainable and genuine results" [25]. Thus, we might hope that future truth commission standards would, for example, include some metric for variety and creativity in institutional design, rather than merely listing particular actions that a TC should recommend.

A useful example of TC standardization is the "citizen approach" to reparations. For many years, TCs focused on prosecution of perpetrators and reparations for victims. However, this method, referred to here as the "victim approach," has some significant flaws, including its lack of acknowledgement of intersectionality. That is, some people are *both* victims and perpetrators, or belong simultaneously to groups labeled as such. Moreover, labels like *victims of sexual violence* tend to exclude men, leaving them without deserved reparations [26]. The victim approach was used in the mandate, methodology, and FR of Timor-Leste's Truth Commission with negative consequences for groups labeled as "victims," especially women [27].

The citizen approach, in contrast, treats all members of the community—so-called victims and perpetrators alike—as active citizens. Under this paradigm, members of traditionally marginalized groups are involved in the reparations process, lending their voices to the recommendations eventually put forward by commissioners [28]. When community members are included in this way, intersectionality is preserved and reparations become

much more effective. For that reason, recent scholarship has included an increased emphasis on the citizenship approach as an effective way to bridge the gap between civil society groups and policymakers while acknowledging the intersecting associations of individuals. This is evidence of standardization.

Of course, at its inception the citizen approach was innovative. The fact that current scholars are drawing on examples of past TCs to determine citizen or victim ideology shows that it is becoming standardized. That is, the *initial idea* to treat all community members as active citizens rather than dividing them into victim groups was *innovative*; ongoing widespread use of this theory shows *standardization*.

An example of proposed standardization (not yet implemented) is the scholarly consensus of the definition of a truth commission [29]. "Scholarly agreement on how to define a 'truth commission' would help researchers create analogous lists of commissions that would test their atrocity-prevention and national reconciliation capacities as well as enhance their design and implementation" [17]. This principle agrees with the concepts outlined by memory-critical scholars because it calls for standardization at the level of the *commission* rather than a prescribed set of memory recommendations that every country should adopt [21].

Additionally, standards such as those presented in *Basic Principles and Guidelines* can potentially prompt increased innovation in TC recommendations. As defined here, a final report that contains evidence of innovation is one that contains at least one memory-related recommendation that is unique to that particular country's FR. Ten of the FRs in this study meet UN standards; of these, six show evidence of innovation according to this definition. In contrast, of the five that fail to meet UN standards, only one shows evidence of innovation. I don't attempt to suggest a causal relationship here; this sample size is clearly not large enough to be statistically significant. However, this principle merits further investigation.

From these examples and the coded data, it is clear that innovation and standardization

both have a role in transitional justice, particularly when recommending historical memory acts.

One commonly cited shortcoming of the field of transitional justice is that it relies heavily on descriptive analysis, including in-depth analysis of case studies, as opposed to systematic, empirical investigation [14, 30]. The data-driven approach of the GTCI helps to address this lack. Still, applying principles from the physical sciences can help to improve the quality and the usefulness of truth commission studies overall.

One direction for further research not covered in this document is the implementation of historical memory recommendations. As Priscilla Hayner says,

> Those countries that have implemented strong, significant programs quickly
> (such as Morocco and Chile) had the political will to do so from the start, and
> policymakers took the lead in crafting significant programs. Where there was
> little political will or policymakers simply did not view victim reparations as a
> priority (as in South Africa, El Salvador, Haiti, or Sierra Leone), the possibility
> of a significant program for victims was limited even with strong pressure from
> organized civil society and victim groups [31].

Thus, even when truth commissions recommend historical memory acts, there is not necessarily a guarantee that those recommendations will come to fruition. It is therefore of interest to TC researchers to determine what specific factors in the mandates and operations of past truth commissions lead to successful implementation of reparations suggested in the final report.

The important thing now is to ensure that innovation is prioritized in the recommendations of future truth commissions. As truth commissions become more prevalent worldwide, the regulation of truth commission mandates, operations, and final reports increases. These regulations must include a call for commissioners to use human-centered design and local

culture to determine what they recommend as reparations. Moreover, once the effectiveness of these recommendations has been established, their *implementation* should be a top priority for policymakers.

3.2   Optimized Spectrometer Configuration

Here, I demonstrate the position of LED bank and detector respective to the radial artery that minimize shot noise from the pulsatile signal. Many factors affect pulsatile signal and shot noise [22]. In this section, I firstly discuss the physical constraints of the spectrometer system. Next, using those physical parameters, I describe the variables that can still be altered. Finally, I propose a complete setup that incorporates all of those parameters in a spectrometer that will maximize pulsatile arterial signal-to-shot-noise ratio.

The primary constraint of the spectrometer is the collimator. Any light incident on the detecting surface of the spectrometer (i.e. in contact with the skin) must pass through a collimator before it is detected. The size of the collimator determines the spectral resolution.[1] For the purposes of the spectrometer system, in order to have enough spectral resolution to discriminate between regions of interest, the collimator can accept angles entering at a maximum of $\pm 30°$ from the normal to the spectrometer's outermost plane.

The ratio of detected signal to shot noise increases as the collimator's accepted angle range increases.[2] Therefore, it is advantageous for signal-to-noise ratio to use a collimator

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[1]This particular collimator "throws away" light incident at an angle wider than its accepted range. Thus, the intensity of detected light increases with an increase in collimator angle acceptance.

[2]This becomes obvious when considered in context of the fact that shot noise increases with $\sqrt{x}$: When the collimator *accepts* light entering at a wider range of angles, it naturally *discards* less light. Because detected intensity is greater at wider angle "bins," signal is higher, while shot noise is *not as much* higher. Numerically, if the signal increases by a factor of x (where $x > 1$) when the angle bins are widened, shot noise increases by a factor of $\sqrt{x}$. Signal-to-shot-noise ratio, $x/\sqrt{x}$, is therefore greater than 1, as hoped.

with angle "bins" as large as possible. We must also remain within the constraints of a maximum of $\pm30°$ given by the spectral resolution. From this, we conclude that the collimator should allow incident light coming in at an angle of $\pm30°$ to the normal to the plane of the spectrometer face.

The next parameter to address is the orientation of the collimator. The default for this is to place the entry plane of the collimator directly on the surface of the skin, with the light propagating perpendicular to the collimator-skin interface as it travels to the spectrometer. However, a simulation of the situation is necessary in order to confirm whether that is advantageous for the overall signal.

To determine the appropriate orientation and location of the collimator, I simulated the propagation of 500,000 photon packets across 70 workers on each of 14 instances. The mean value of the pulsatile arterial signal-to-shot-noise ratio was 2.323×10^{-3} (this is a ratio and therefore a dimensionless quantity). The minimum value was 1.027×10^{-3}. The highest value of pulsatile arterial signal-to-shot-noise ratio was 3.488×10^{-3}, found when the collimator is placed at a location of 1.0 mm from the artery in the -x direction and at an angle of 3° from the normal in the +x direction. A visual representation of these values is shown in Fig. (3.2).[3]

With the collimator oriented thus, pulsatile arterial signal-to-shot-noise ratio is maximized with the detector placed 1.0 mm[4] away from the projection of the radial artery on the skin and the source placed 2.5 mm away from the detector (on the opposite side of the artery), where the line between the center of the detector and the center of the LED bank is

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[3]The uncertainty in these values is quantifiable. However, it is too complicated to attempt to display visually in the figure. The numerical uncertainty of these values is far less than the precision to which we can control the physical system; therefore, it does not merit significant discussion in this portion of the paper.

[4]As noted in Chapter 2, source and detector positions were simulated every 0.5 mm. Thus, values given here are accurate to the nearest 0.25 mm.
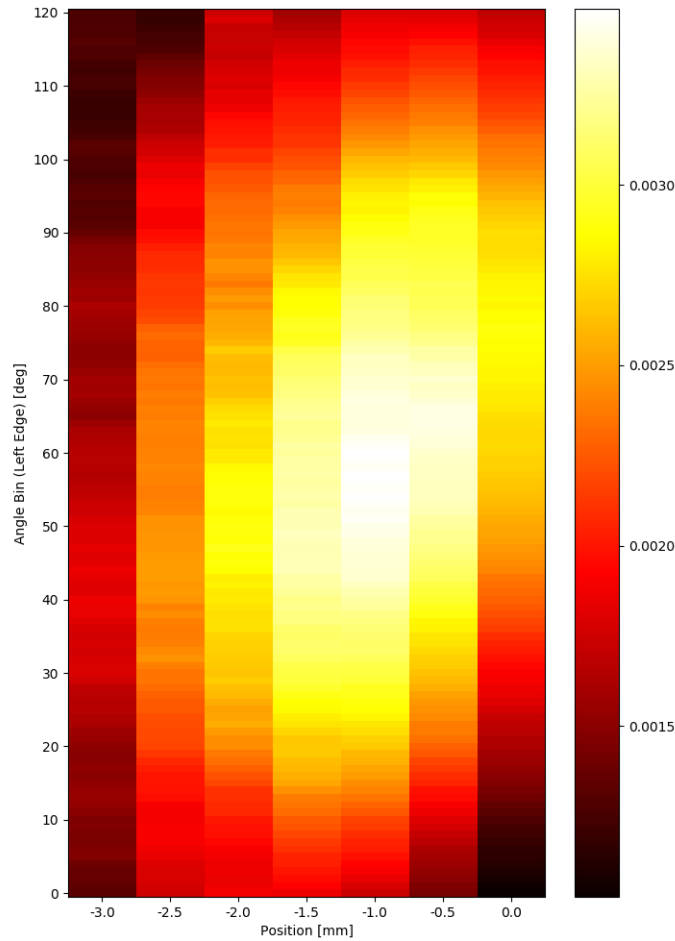
Figure 3.2 Simulated pulsatile arterial signal-to-shot-noise ratio by photonic incident angle at spectrometer and spectrometer position relative to the LED bank and radial artery. Light is simulated at 1600 nm. Heat map values correspond to the difference between photonic energy detected with systolic artery pressure and photonic energy detected with diastolic artery pressure, divided by the square root of the average of systolic and diastolic photonic energy, shown in Eq. (2.1).

orthogonal to the arterial projection.

Furthermore, an off-axis focusing Fresnel lens should be placed between the LEDs and the surface of the skin to focus incoming light to the back of the artery in the direction of the detector. When input light is focused this way as compared to an isotropic hemisphere, simulated values show a fractional increase of 8.044×10^{-1} in the arterial signal-to-shot-noise ratio, with a fractional error of 1.807×10^{-2}.

The crux of the issue, then, becomes this: It's really difficult, in practice, for someone to place a device on their wrist to an accuracy of 0.5 mm. Thus, no matter how good the science is or how well the physical spectrometer matches the simulated ideal, we are still limited by user operation. This is the knowing-doing gap: even if people know the best treatment method for them, there are many reasons why they might not do that [5]. Phrased differently, *without participatory, action-based research, we cannot be sure that this device has accomplished its purpose*.

A recent study of adolescent healthcare practices describes its use of human-centered design as follows:

> Across five sessions (four video conference calls, one in-person workshop), we used systems mapping to identify key stakeholders and their relationships, processes, and challenges to care; formed clinic staff-investigator design teams; brainstormed about challenges that would influence intervention implementation and considered potential solutions; prioritized implementation challenges; and designed prototypes of solutions [32].

All of these methods (systems mapping, workshops, design teams, prototyping, etc.) merit consideration for participatory research in designing a continuous glucose sensor.

Human-centered design, focused on helping individuals and working within the framework of culturally acceptable models, has already been a driving force in this project. This is evidenced in the framework of the project itself: Smartwatches are already commonly used in our society, so designing this medical sensor to blend in as just another smartwatch is culturally appropriate. In addition, prototypes have been made and tested on participants for user feedback and design improvement. In order for the goals of the device to be met, similar design principles must be implemented at every stage of the process.

3.3   Conceptual Interdisciplinary Links

The two subjects under consideration in this document—computational optics and historical memory—are different in many important ways. The vast differences in these topics are the reason why the majority of the document is neatly divided between the two. However, there is significant value in an interdisciplinary approach.[5]

One link between TCs and the glucose monitoring project is, as implied by the title, measuring unseen harm. High or low blood sugar can cause harm to a person's physical body; we're trying to measure those levels to minimize harm. Conflict can cause emotional, mental, and psychological harm to a person in addition to physical harm; by having a TC, we are better equipped to understand who has been harmed and how.

Another link that binds these two topics together is that they both present techniques to cope with a problem. Both projects take a "pulse" (either a metaphorical community pulse or a physical individual pulse) and give information meant to guide solutions, either as biometric data or a TC final report. Moreover, the glucose research, using computer modeling to track the path of light through skin, gives information about something that you wouldn't know just by a physical experiment; similarly, truth commissions look "beneath the surface" to see the root sources of post-conflict problems. In both cases, we get information about things that we wouldn't know just by looking at the situation at a macro level.

There are metaphorical connections between these two topics, as well. Light, for instance, has an obvious physical significance in the glucose monitoring project: We use light to gather data about the properties of blood. TCs, in a more metaphorical sense, "shed light" on atrocities committed in a country as a form of transitional justice. Moreover, both TCs and non-invasive glucose monitoring are meant to show the truth about what's happening to

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[5]One might even say that addressing these two subjects together is evidence of innovation in academic writing.

an individual or a group with the goal of measuring progress and problems and then fixing those problems.

Historical memory is a way of tracking patterns; by drawing a tie from the past to the present, communities are better able to plan for the future. Similarly, if an individual has more information about their own blood sugar history (which they could obtain via the continuous glucose monitoring sensor), they become better equipped to take care of their health moving forward. In a similar vein, having more knowledge—truth—makes individuals better able to take care of their physical health and countries better able to take care of their community health.

Since both topics deal with data-driven investigations, measurement is another valuable connection between them. Blood glucose measurements give a concrete value for what is happening within a person's body; that number tells the person whether they are within "healthy" range or without it. A TC also makes a measurement, though it is less quantitative. Both measurements are vital for understanding the overall health of the system.

The balance between innovation and standardization applies to both projects as well. The GTCI was created to be one standard for measuring particular aspects of a TC; the present study of historical memory in a FR can also contribute to that purpose. This method compares each TC to others of a similar caliber, using global norms as the standard for measurement. While this is a good way to compare TCs and get general data about what is contained or not contained therein, it's not necessarily valid for assigning a value judgment to a particular TC, because every country has such specific needs. Standards are somewhat different for glucose measuring. The American Diabetes Association, the Center for Disease Control and Prevention, and other national-level governing bodies have published data about concrete numerical standards for healthy blood sugar levels [3]. These standards are fairly constant for all people. However, there will still theoretically be valid ranges for the glucose

measuring device itself—how accurate it is supposed to be, what it can and can't measure, where its measurement fails—and these standards will be more akin to those measuring a TC.

Furthermore, any scientific endeavor mandates the validation of the measuring tools themselves. As a scientist, I must be critical about the tools I use for measurement. If our spectrometer system is the standard for measuring blood glucose, and a truth commission is the standard for measuring the health and healing of a community, there must be a way to validate each of these types of experimental "equipment" to ensure that they are providing accurate information. As of right now, the only method by which to judge the type of measurement we are attempting is via computational modeling; i.e., by Monte Carlo simulation. The only current method we have for judging the quality of a TC is through comparative analysis. Thus, both of the projects examined here offer a way to validate data-taking methods.

I would be remiss to conclude this section without mentioning uncertainty. There are errors in every measurement, so it is important to maximize the signal-to-noise ratio in order to ensure that you are measuring what you intend to measure. In determining blood glucose levels non-invasively, there is a lot of background signal (that is, light detected from outside sources or light not modulated by pulse) [4]. When investigating unseen harm in a post-conflict country, the "background signal" (unimportant details, political agendas, disagreements in historical records, etc.) becomes almost overwhelming. This raises two critical questions that are valid for both topics; namely: (1) How can we be certain that what we're measuring is the thing we set out to measure? (2) How do we quantify our uncertainty?

3.4 Conclusions

The conclusions drawn from historical memory in truth commissions help to inform conclusions about the spectrometer system, and vice versa. By incorporating social science techniques into the process of designing a noninvasive glucose sensor, the sensor becomes more useful and better fulfills its intended purpose. Applying quantitative analysis to the field of truth commissions sheds light on the events covered by the truth commissions themselves and also improves the overall methodology of this transitional justice mechanism.

An interdisciplinary, human-centered design strategy can help investigators address the challenges inherent in both of these projects and design services that can actually be applied in the user experience. That is, human-centered design helps by shedding light on the most important application-based factors in a project. No matter how good the science of the spectrometer system is, if people don't know how to implement it properly, it won't be useful. And no matter how helpful a historical memory recommendation is, if it's not culturally appropriate, it'll cause more harm than good. Thus, in both cases, the application of human-centered design principles focuses investigators' attention on user issues and helps ground the scientific process in real-life solutions.

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