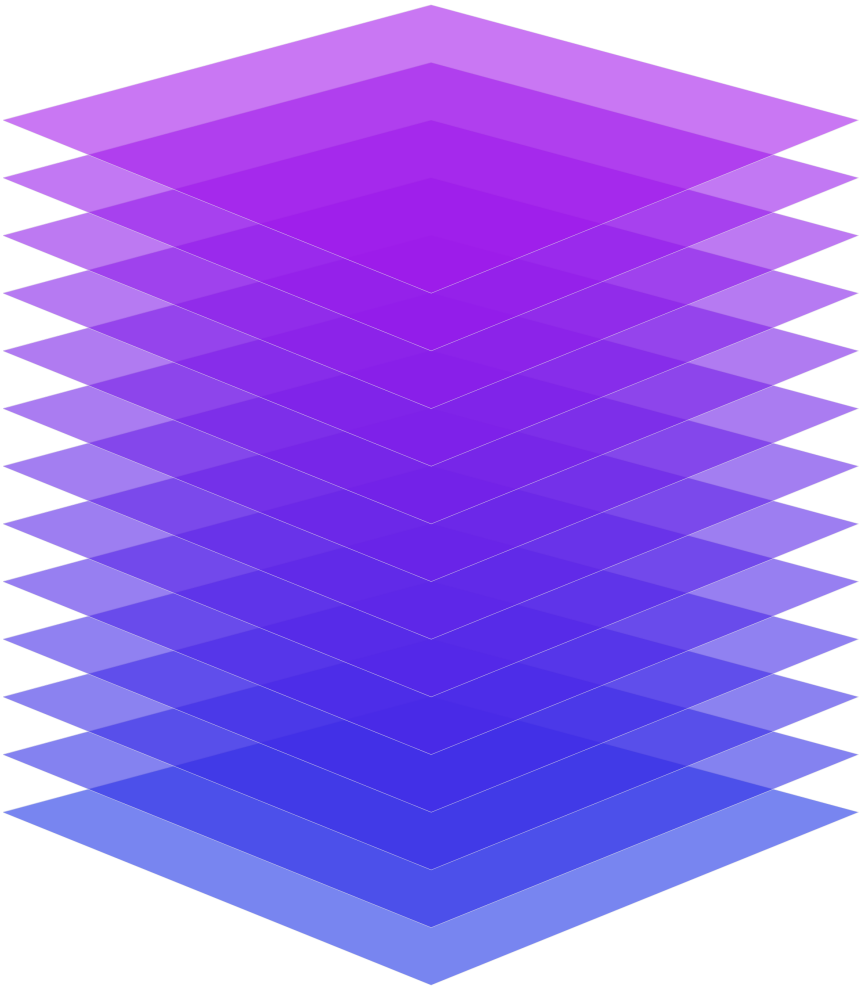

SMU JOURNAL OF UNDERGRADUATE RESEARCH

VOLUME 2 | SPRING 2016

Dedicated to the memory of Dr. John L. McCarthy, professor *emeritus* of biological sciences.

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SMU JOURNAL OF UNDERGRADUATE RESEARCH

VOLUME 2 | SPRING 2016

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SMU Journal of Undergraduate Research (*SMUJoUR*)
Volume 2 | Spring 2016
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Letter from the Editor

Dear Reader,

I am proud to present to you the second edition of the *SMU Journal of Undergraduate Research*, which we've affectionately taken to nicknaming *SMUJoUR*. *SMUJoUR* seeks to shine a spotlight on the rigorous work of SMU's talented undergraduates. Education at SMU extends far beyond the classroom: into the field, into the archives, and into the lab. Our students spend months leading research that spans a wealth of disciplines and the interdisciplinary interstices that unite them. In producing this journal, the SMU Honors Research Association (HRA) aims to increase the awareness of these students' diligence, in our own community and the larger academic discussion.

As with any sequel, the question arises: how do you bring a good thing back and make it better? First, HRA implemented an impartial double-blind review process. You will also find increased breadth: articles from the Dedman College of Humanities and Sciences, the Cox School of Business, and the Lyle School of Engineering. Beyond these things, we feel a personal victory in being able to offer *SMUJoUR* in print for the first time. As you turn its pages, may you take as much pleasure as we did in delivering it to you.

Though improved, this journal will still feel familiar. As always, you can expect depth and breadth: stunning research in a variety of fields. You will learn of breakthroughs in topics to which you may have scarcely given any thought. These students' work is meaningful, not menial. Also, in this entirely student–run publication, student submissions from all fields are collected, reviewed, and curated: in addition to highlighting student researchers, our editors are honing the art and process of submission, revision, and publication.

Voltaire said, "Appreciation is a wonderful thing. It makes what is excellent in others belong to us as well." The excellence of many has contributed to this year's edition of *SMUJoUR*, and acknowledgments have been heartily earned. I would like to thank our submitters, as well as their mentors and advisors, for providing us with the content to dive into. Further thanks go to my fellow editors and our review board, for their relentless effort this past year in readying these papers for your reading pleasure. Without the support of Dr. Steven Vik, the genial faculty sponsor of HRA; Dr. Bob Kehoe, Director of Undergraduate Research; Farley Ferrante; Courtney Zanetti; Juan Ramirez; and of course Engaged Learning's Susan Kress and Mona Alluri, this work would still be a pipe dream. Above all, I must recognize the vehicle for all our successes: our beloved university, SMU.

Finally, thanks to you, reader, for your attentiveness to research at SMU. Read on.

Arya McCarthy ('17)
SMUJoUR Editor in Chief

SMU Honors Research Association

In the tide of growing undergraduate research interest, SMU HRA was founded in 2013 as a student organization with the mission of growing research involvement and awareness on and off campus, creating a better undergraduate experience and raising the scholastic caliber of SMU. We are an interdisciplinary community of scholars, growing the span and visibility of undergraduate research and championing projects that enrich the undergraduate research experience.

With the surge of undergraduate opportunities on campus and afar, SMU HRA provides a centralized resource for both new and experienced student researchers to explore and pursue these opportunities. SMU HRA maintains a labs database, connecting assiduous undergraduates to faculty researchers. We produce both the *SMU Journal of Undergraduate Research* and SMU's creative and literary publication, *Kairos*. Submissions are accepted year-round on our website.

SMU HRA is the gateway to research involvement and professional development. With speaker events, faculty panels, and workshops, we enable and celebrate students' investigation of their passions. Join us at smu.edu/undergradresearch.

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The Hamilton Undergraduate Research Scholars Program enables Dedman College's most promising students to collaborate with top faculty researchers and contribute to the creation of knowledge in significant and meaningful ways. Each faculty/student team submits a competitive proposal for the project to the Program Director in response to a call for proposals in August of each academic year. A small number of Hamilton Undergraduate Research Scholar Awards are also made for the summer with a request for applications going out in late April. Awards are up to $3000/semester with matching funds available from the University Undergraduate Research Program.
www.smu.edu/Dedman/DCII/Programs/Hamilton

Robert Mayer Undergraduate Research Fellowships through the Dedman College Interdisciplinary Institute allow students to conduct research integrating two or more fields. Mayer Interdisciplinary Fellows will have access to $1500 to use for research travel or for other expenses related to the development and completion of their research project. There will also be funding available for the student to attend an appropriate scholarly conference to present their work and interact with others working in their field(s).
www.smu.edu/Dedman/DCII/Programs/Mayer

John G. Tower Center Student Fellowships provide a gateway for students to pursue work in politics and government. Undergraduate Fellows collaborate closely with faculty to develop research projects that either become published or presented for faculty or professional review. Fellows are accepted during the second semester of their sophomore year and serve as fellows during their junior and senior years. Selection is based on merit and determined by an application and interview process emphasizing ability and interest in research. Each fellow receives a stipend of $750 per semester for a up to four consecutive semesters, a book allowance for documents related to the independent study project, and support for research expenses.
www.smu.edu/TowerCenter/Students/TowerScholars

Big iDeas Grants are designed for entrepreneurs. Teams of students pitch their business and design business plans, helping students bring a value to society in viable and sustainable ways. This work also satisfies University Curriculum requirements. Students can receive up to $5000 in funding.
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Maguire Public Service Interns are sponsored by the Maguire Center. The Maguire Center—with financial assistance from the Irby Family Foundation—awards summer internships to SMU students who wish to devote time to public service or research in the field of ethics. SMU Public Service Interns have volunteered in a vast number of diverse internship placements. Through such opportunities, students gain concrete information about others' needs, as well as differing perspectives on how to resolve them. Undergraduates receive a $2000 grant for their internship.
www.smu.edu/Provost/Ethics/Students/Fellowship

Engaged Learning takes learning to the ultimate level through student-driven, goal-oriented projects anywhere in the world. Students' projects include undergraduate research and community service. Students also engage in internships and creative activities. SMU publishes student work in the Engaged Learning Collections, celebrates student achievement at graduation, and posts projects on transcripts. Students receive up to $2000.
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The Richter International Fellowship Program is funded by the Paul K. and Evelyn E. Cook Richter Memorial Funds and is awarded to members of the University Honors Program to conduct independent research, usually outside the United States. The project can cover any area of study, but should be international or multicultural in nature. SMU is one of only 12 schools offering Richter Fellowships, and only Honors students are eligible for the Fellowships. Richter Fellows receive funding for one to three months of research over winter or summer break, generally abroad. Upon returning, Fellows write and submit a scholarly article based on their research with intent to seek publication.
www.smu.edu/UndergradResearch/Programs/RichterFellowship

Summer Research Assistantships (SRA) are an excellent way for a student researcher to make focused progress in a project, whether devising a new project or continuing one from the academic year. The writeup can be published in the *SMU Journal of Undergraduate Research* or other publications. SRAs allow students to earn up to $4000 for the summer, providing matching funds to departmental or grant money, Engaged Learning, Hamilton, or McNair Scholars.
www.smu.edu/UndergradResearch/Programs/SRA

Undergraduate Research Assistantships (URA) provide an opportunity to students to pursue research across all disciplines. By providing matching funds to another source of research funding, such as a department's, school's or individual faculty member's existing research funding, this program facilitates undergraduate involvement in the university's leading– edge research. Each assistantship involves a student working closely with a faculty member. Applications for URAs can be submitted at any time. During the academic year, support for up to 10 hours of research each week is provided.
www.smu.edu/UndergradResearch/Programs/URA

An Optical Search for Variable Stars Using ROTSE–I and ROTSE–III Telescopes

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1 Introduction

In the observable universe, it is estimated that there are on the order of a trillion galaxies, which may contain up to a trillion stars each. In total, there may be 10^{24} stars in the universe, 50% or more of which are variable stars: stars that change in brightness over time. There are many types of these stars in existence throughout the universe: Mira type variables are a class of pulsating red giants that are in the late stages of stellar evolution and could come to emulate the end of our Sun's life cycle. Binary stars such as nova–like Cataclysmic type variables form accretion disks and can help us study the traits of larger scale accretion physics, such as in neutron stars, white dwarfs and even black holes. SN Cataclysmic variables, also known as supernovae, can provide an accurate measurement for cosmic distances along with Cepheid variables. Studying the multitude of variable stars that exist can help astronomers understand the mechanics of physics in foreign environments, and can help map our surrounding galaxies. The analysis of variable stars provides specific information about the stars, such as their mass, luminosity, temperature, internal and external structure, composition and evolution. Because the number of variable stars is so large, with each star requiring dedicated observation time, the community of researchers is also large and diverse, consisting of several ground based telescopes, as well as hundreds of physicists and professional or amateur astronomers. SMU studies variable stars and other celestial phenomena through the use of our own robotic telescope and the efforts of undergraduates, graduate students, and professors in the Physics department.

*Mentors: Dr. Robert Kehoe & Farley Ferrante, Dedman College, SMU

2 Project Description

The overall purpose of the summer research experience was observation and data mining with robotic telescopes in order to discover and study variable stars. This included data from SMU's Robotic Optical Transient Search Experiment – I (ROTSE–I), in order to search for the undiscovered variable stars [4]. Once a suspected variable was successfully analyzed, it was then submitted for classification and discovery to the International Variable Star Index (VSX), a database sanctioned by the International Astronomical Union and created by astronomers for the purpose of maintaining a globally accessible catalog of discovered and suspected variable stars. Once submitted, a star would wait for approval by a moderator. The VSX moderators had the ability to accept the variable star as a new discovery, or reject it with the justification that the data or analysis required improvement. After spending some time with the ROTSE–I's four camera fields, the goal was to move onto the new ROTSE–III telescope and use its unanalyzed raw data contained on SMU's High Performance Cluster to create files that others could use to discover additional variable stars, while discovering stars of my own as a proof–of–concept [1].

In order to analyze the data used to discover variable stars, a working knowledge of some computer science was first required. The archived data for ROTSE–I is stored in the SMU physics department on computers that run Linux as an operating system. Data manipulation occurred through the use of the programming language known as the Interactive Data Language (IDL), which is popular in the fields of astronomy and atmospheric physics, and is adept at handling large amounts of data. Some of the files used during the variable star analysis contained thousands of lines of information, which catered towards heavy use of IDL. Once in the correct Linux directory where the files where contained, IDL could be used

to create postscript files (.ps) that allowed for visual data analysis. These .ps files contained a multitude of plots, each of which displayed an object's brightness versus observation time, as shown in Figure 1.

On the y–axis of each graph is the star's magnitude, which is a logarithmic measurement of its brightness. It is built on an old system introduced by Hipparchus circa 130 BCE: stars visible to the naked eye were divided into six classes or magnitudes, in accordance with their brightness [3]. The brightest stars were placed into the first class and thus were given a magnitude of one. The dimmest stars were classified as sixth magnitude, which means that they were the limit of human vision in perfectly dark conditions without a telescope. The system was updated in 1856, when astronomer Norman Pogson defined that a sixth magnitude star was 100 times dimmer than a first magnitude star. Thus, in accordance with the logarithmic scale established, each star is $\sqrt[5]{100} \approx 2.5$ times brighter than the star of a magnitude before it. Because a larger magnitude value indicates a dimmer star, it is important to note that in the graphs of Figure 1, a star gets dimmer as it moves downward on the y-axis, and brighter as it moves up on the axis. These graphs displayed are known as light curves, they are used to visually inspect variations in brightness over time. Each graph has its respective observation object number and spatial coordinates listed above it. The coordinates used are taken from the equatorial coordinate system, where objects are given a position based on their angular distance from a geocentric reference point. The first number is known as the object's right ascension (α) and it corresponds to the east/west direction, whereas the second number, declination (δ), measures north/south direction. Right ascension specifically measures the angular distance to an object eastward along the axis of earth's equator, beginning from the vernal equinox. It is measured in hours, minutes and seconds. Declination measures the angular distance of an object perpendicular to the axis of the earth's equator. It holds a positive value to the north, and a negative value to the south. Declination is measured in degrees, arcminutes and arcseconds. As a convention, coordinates in names are specified down to two decimal places in right ascension, and only one in declination. The equatorial coordinate system can be used to search for specific stars in a variety of web services, such as VSX, SIMBAD, and Aladdin. Thus, before pursuing an in depth analysis of a possible variable, sources that show variation in brightness have their coordinates entered into VSX's database to check if they have been previously discovered. For example, in Figure 1, the bottom right image clearly demonstrates a variation in brightness over the 0.4 day observation period. This makes it a promising candidate for variable star status. Thus we enter its coordinates into VSX to see if it has been discovered or not. Entering 122103.89+361651.8 into VSX shows that this specific star was discovered in 2005; this pushes analysis of the star back, as priorities are given to undiscovered variables.

If the coordinate search of a promising light curve returns a page with no discoveries listed, then the star is listed on the ROTSE website for pending discoveries and further analysis is pursued. The first step in the process is to check for the same coordinates in the remaining nights of observations in order to see if the star made it into the images taken by the ROTSE telescope. If the star's coordinates are listed in several nights, with each night's light curve showing some sign of variation in brightness, then a phased light curve can be built for the star. IDL is then used to extract three columns of data from each observation through the use of the command find_burst, which outputs data based on cuts given by the user. These cuts manipulate specific statistical processes, namely the variation in brightness magnitudes (Δm), the significance of the maximum variation (σ_{max}), and the chi-squared value (χ^2) with respect to a constant brightness. The variation in magnitude parameter, Δm, is the difference between the brightest observed magnitude and the dimmest for the light curve. This cut is typically selected to be ≥ 0.1. The significance of the maximum variation (σ_{max}) is the difference in magnitude divided by the estimated uncertainties on the magnitude summed in quadrature:

$$\sigma_{max} = \frac{\Delta m}{\sqrt{\epsilon_{max}^2 + \epsilon_{min}^2}} \tag{1}$$

where m refers to magnitude, while ϵ refers to the the estimated uncertainty in magnitude. The significance in maximum variation cut attempts to determine if an observed variation is significant by checking to see if it is large compared to the uncertainties on the measurement. It is usually restricted to be ≥ 3. The chi-squared value (χ^2) is a measurement of the agreement between an observed distribution of measurements and the Gaussian distribution expected for the measurements:

$$\chi^2 = \sum_{k=1}^{n} \frac{(m_k - -\overline{m_k})^2}{\sigma_k} \tag{2}$$

The summation is performed over all measurements k, while the m and σ parameters denote the magnitude and estimated uncertainty in magnitude

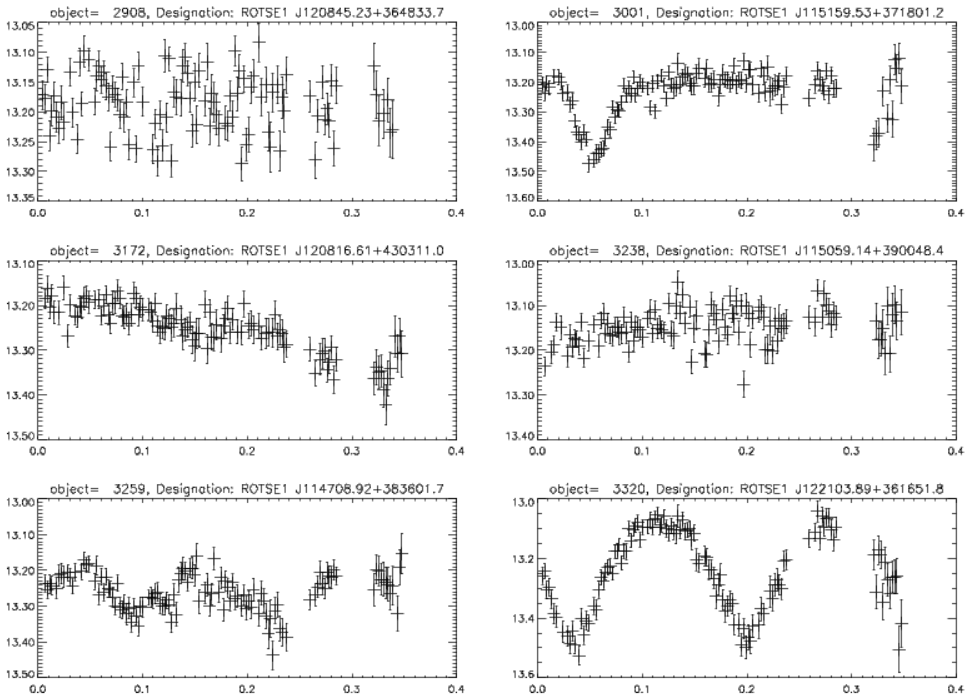

Figure 1: A sample .ps file that displays the light curves of some celestial objects.

for each measurement, respectively. The average magnitude, $\overline{m}$, is taken over the entire light curve. This process rejects light curves where just a single measurement is bad. If the star recorded is not a variable, the chi-squared valued will be $\approx$1. In find_burst, the chi-squared selection is usually set at 2.0 [2].

The find_burst command gives three data columns as output: the date the observation was recorded, the brightness of the star, and the error on the brightness value. The date system that astronomers use is called the Julian Date system (JD), and it is simply a continuous count of days and their fractions since noon Universal Time on January 1, 4713 BCE [9]. Because of the large amount of time that has elapsed since the beginning of Universal Time, the Julian Date time is now in the area of 2.5 million days. As such, astronomers introduced the Modified Julian Date (MJD) in the late 1950s, defining it as MJD = JD $-$ 2400000.5, which shortens the amount of numbers necessary to describe a date, and changes the "start" of the day to midnight in conformance with civil time reckoning [10]. Once the three columns of data were extracted from each night of observations by IDL, they were then combined sequentially in accordance with the MJD dates into one large file. This large file was run through the single_phase command, which combined the light curves from each night into a single "folded light curve" using a cubic spline fit algorithm [4]. These folded light curves also allowed the variable star's period and amplitude of variation to be determined, as shown in Figure 2. This single phase command was especially important, as we learned that our cubic spline fit did not always produce the correct period for the variable star. Instead, the given period sometimes halved or doubled the true period, and would require a search for correct period values using the CRTS and LINEARb telescope's phasing tools found on their respective websites.

Figure 2 is composed of two distinct graphs. The upper half displays the variation and magnitude range of observations from each individual night. The lower portion shows the light curve, which is a plot of brightness versus phase or period. Each integer value on the phase axis (1.0, 2.0, etc) denotes a full period of variation for the star. Also displayed on the light curve are the period and amplitude values for the variable star, with the period value listed in days. These numbers are important in defining certain properties of variables stars, and are necessary for submission to VSX. The moderators at VSX do not just want SMU's folded light curves for submission, they prefer additional data sets plotted in conjunction with ROTSE data in order to confirm our initial findings. These data sets can be found on the websites of telescopes that have publicly released data sets, such as SuperWASP, Catalina Real-Time Transient Survey

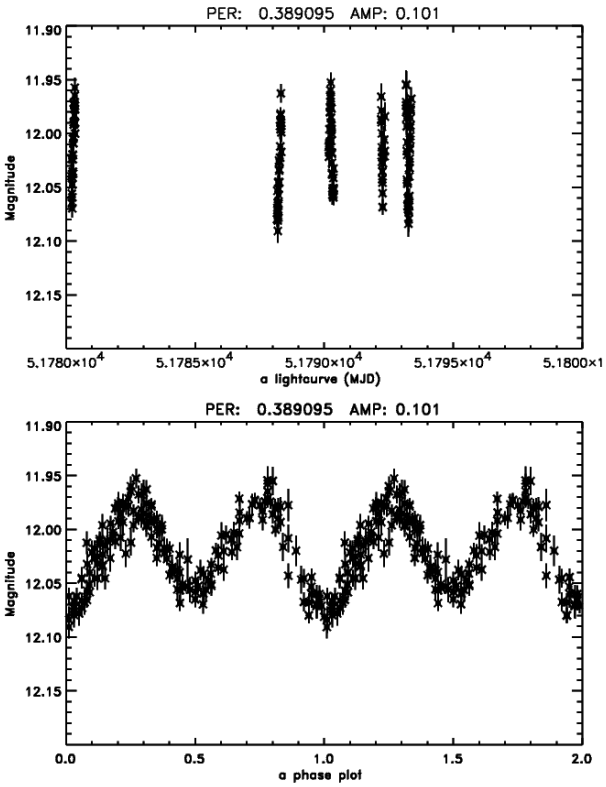

Figure 2: A Folded Light Curve of ROTSE1 J000459.91+233315.0.

(CRTS), LINEARb, or Northern Sky Variability Survey (NSVS). These websites often have data available in the three column format of date, magnitude and error on the magnitude, so the analysis process for each telescope was nearly identical to that of standard ROTSE variables. Once these data sets were run through IDL commands such as single_phase, they had their own folded light curves produced. If the period values differed by a large amount around the fifth decimal place in the two light curves, then the data sets were combined and then run through IDL analysis together in order to produce a lightcurve that used average data from multiple data sets, thus creating a more accurate plot. Once an accurate period was achieved, a separate software called gnuplot was invoked to produce the final light curve that would be submitted to VSX. Figure 3 displays SMU's ROTSE dataset plotted on top of a SuperWASP dataset to show that both follow the same trend in variation.

Submitting variable stars for discovery to VSX requires more than just a phase plot, period and amplitude of a star. VSX also requires the type designation of the star, the magnitude range, additional names or catalog designations of the star, and other references. The type designation of the star depends on

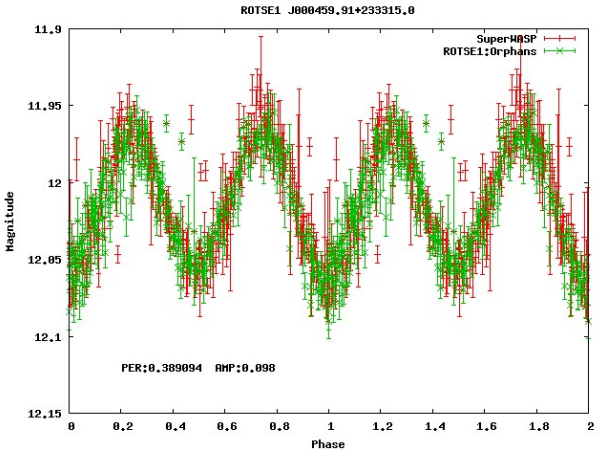

Figure 3: A combined Phase Plot for ROTSE1 J000459.91+233315.0

the star's amplitude, period and shape of the light curve. There are a large amount of classification possibilities for variable stars, with each sub–type having its own characteristic light curve or period and amplitude values. The star in Figure 3 was classified as an ELL variable, which denotes a binary system with ellipsoidal components, which varies its brightness due to changes in emitting area towards an observer. The light curve shape is indicative of rotating variable and its amplitude not exceeding 0.1 magnitudes in variation helps classify it as an ELL [6]. After classifying the type of variable star, additional observation sources are required. These can be found through the clearinghouse of astronomical catalogs known as VizieR, which maintains a record of astrometric observations and references gathered from a plethora of surveys. Once these categories have been completely determined, the new variable discovery can be submitted to VSX and sent to the moderators for approval.

3 Results

As a result of the summer research project, SMU had its first variable stars discoveries of 2015. The first star I discovered was ROTSE1 J114708.82+383602, which was listed as an EW. EW stars are W Ursae Majoris–type eclipsing variables, with brightness variation periods shorter than one day. This means that the two stars in the system complete an orbit around their common center of mass in less than a day, which shows just how close to each other, and how fast these objects are moving. Ursae Majoris type variables are contact binaries, and as a result, change brightness levels due to the stars eclipsing each other twice ev-

ery period. The second discovery of the summer was the star ROTSE1 J112206.29+375441.9, also listed as an EW due to the shape of the light curve and due to the period staying below the threshold of one day. The third object to come out of the ROTSE–I field was not a discovery, but a type update. NSV 19084 was a variable star discovered in 1959, however, very little data was made available about the star itself. The star's type, period, amplitude, maximum magnitude values and even phase plot were absent from the VSX catalog. ROTSE–I was used to update the variable star's entry in VSX and thus filled in the missing data sets. The star itself was classified as an RRAB, which means it is a pulsating RR Lyrae type variable, characterized by asymmetric light curves. The pulsating classification denotes a star that is periodically shrinking and expanding in size, which causes it to change in brightness. After the pulsating star was updated in VSX and approved by the moderators, another pulsating star was found, this time having been previously undiscovered. ROTSE1 J232708.22+371216.9 was determined to be a HADS, a high–amplitude Delta Scuti variable. These stars are radial pulsators with asymmetric light curves and amplitudes less than 0.15 magnitude in variation. Delta Scuti variables, sometimes called dwarf Cepheids, are important standard candles that have been used to establish the distance to the Large Magellanic Cloud, as well as the Galactic center [5]. The last ROTSE–I discovery was ROTSE1 J115159.50+371801.3, an EA variable which denotes a semi–detached binary system with a characteristic light curve that enables viewers to determine the moment that eclipses begin merely at a glance.

After spending a large portion of the summer analyzing ROTSE–I data, the project shifted focus to the more recent ROTSE–III telescope. The variable star discovery process was lengthier with ROTSE–III than with ROTSE–I, as the recent telescope had not yet undergone a formal set up for large scale variable star analysis at SMU. This means that the only data files that existed were the actual raw images taken by the ROTSE–III telescope during its observation nights, thus additional analysis techniques were necessary to create the light curves (such as in Figure 1) and data readouts used in the ROTSE–I processes. The ROTSE–III variable star identification processes began by cutting the pictures taken by the telescope into smaller sections that contained less data, which were then more manageable with the algorithms used. The images taken each night contained too many stars as it was determined that the algorithms could only deal with 1000 stars at a time, which in turn decided the size of our sub–images. The process for making these sub–images involved first selecting a star

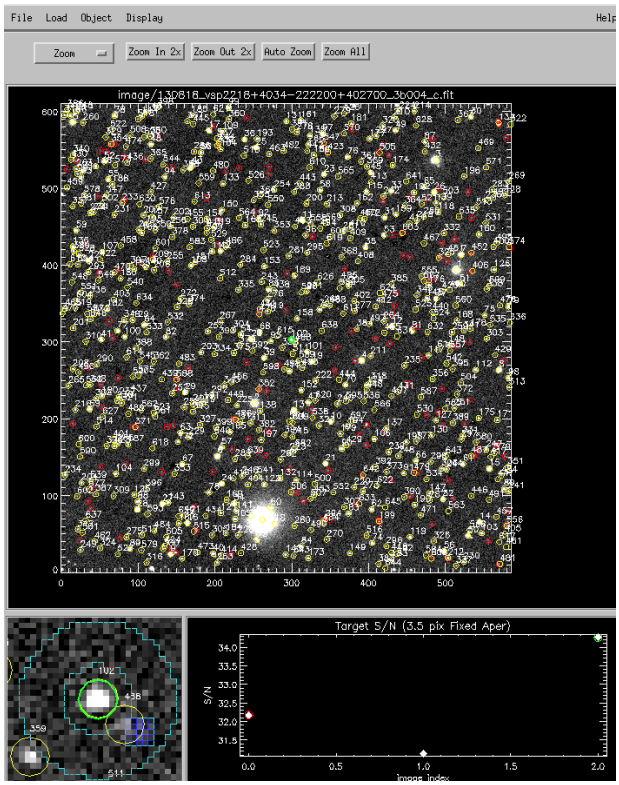

Figure 4: A sub image created with IDL and viewed through RPHOT. The centered reference star is circled in green.

to center the image around. This could be done by viewing the image files through a program named SAOImage DS9, which gave the right ascension and declination values of any point in the image that the computer mouse cursor hovered over. Once the coordinates were recorded, IDL could be used to make the sub image of a pre-defined size using the command make_rotse3_subimage. One such sub image is displayed in Figure 4.

Upon completion, the IDL command that created a sub image would output two types of files: .fit files and .cobj files. Cobj files are calibrated object lists that contain information about the properties of each object contained within the subfield. FITS stands for A Flexible Image Transport System; these files contain match structures, which are compiled data sets that are matched by the position of objects within various images [8]. The .fit files were used in the next step of the ROTSE–III analysis through the use of a relative photometry program (RPHOT) in IDL [7]. RPHOT used the first of the sub images created beforehand to allow the user to input the coordinates of the centered star chosen previously. After doing so, the program would use the remaining stars in the im-

age as references against the centered star. RPHOT's analysis would cycle through each observation until it ran through the entire night, with each observation creating a point on the final light curve for each object. After running RPHOT, a new .fit file would be created that could be used to create light curves such as in Figure 1 through the use of IDL and the find_burst command. After finishing analysis in RPHOT, the variable star identification and submission process became the same as with ROTSE–I. The main goal of the ROTSE–III portion of the project was not necessarily to discover variable stars (though several were identified), but to create a large amount of sub images and .fit files so that variable star analysis could be easily approached by future and current students working on the project. As a result of searching through the created sub–images, several ROTSE3 variables were accepted for discovery. ROTSE3 J222210.88+404033.4 was an EW variable that was accepted for discovery with its only supporting data set coming from CRTS. This established a trend, as most variable candidates from ROTSE3 would end up having little to no supporting data sets from other telescopes. The second ROTSE3 discovery is referenced in Figure 5, and is listed in VSX as an EW type variable under the name ROTSE3 J222125.07+403412.9. In addition to searching for new ROTSE3 discoveries, I also began the task of clearing out the ROTSE discovery backlog. Throughout the years of running data analysis with multiple undergraduates and graduate students, several stars got stuck in a limbo state known as discovery pending. This usually meant that they were submitted for discovery and subsequently rejected by the moderator due to errors in presentation, star classification or data analysis. One of these stars was ROTSE1 J110157.57+460657.9, which was originally submitted in 2012 with incomplete data analysis. It was an EA type variable, which meant that it was more complicated to phase than the usual EWs that ROTSE finds. After reworking the data with additional information from supporting telescopes, a new period and phase were obtained and an updated light curve was submitted and accepted for discovery. Two stars remain in the pending list, and are currently being worked for resubmission.

Throughout the process of creating the sub–images in the ROTSE3 image fields, several interesting variable star candidates were obtained. However, none of them had enough continuous nightly data in order to create a complete and distinct lightcurve. Through the use of the RPHOT process, specific stars could be singled out for comparison to other stars in the field, and thus have additional data generated for the purpose of creating lightcurves. This method allowed for additional stars to be pulled from the ROTSE3 image fields and thus a process was established for extracting discoveries from datasets that did not feature frequently reappearing stars. The submission of stars from these data fields often required more moderator input from VSX than with previous submissions, as the fields are more sensitive to dim stars than with ROTSE1 and thus are less likely to have supporting datasets from other telescope systems such as SuperWASP and CRTS. This creates an emphasis on finding stars that have several observation periods with clean data, as the variability trends need to be clear and distinct in order to provide evidence for variable star classification on their own.

The last portion of the variable stars project involved writing a guide with a twofold purpose: firstly to establish a set process for variable star analysis, and also to consolidate every piece of relevant information that was originally spread out through various documents. The guide took information from emails, text files, various websites and even feedback from VSX moderators and combined it into a convenient report that could be referenced by other students working on the project in the future. The guide is written to cover ROTSE1 and ROTSE3 processes, and will continue to expand into other areas as needed in the remaining weeks of the Engaged Learning project.

Table 1 summarizes entirety of variable star discoveries during the summer of 2015 and the 2016 school year.

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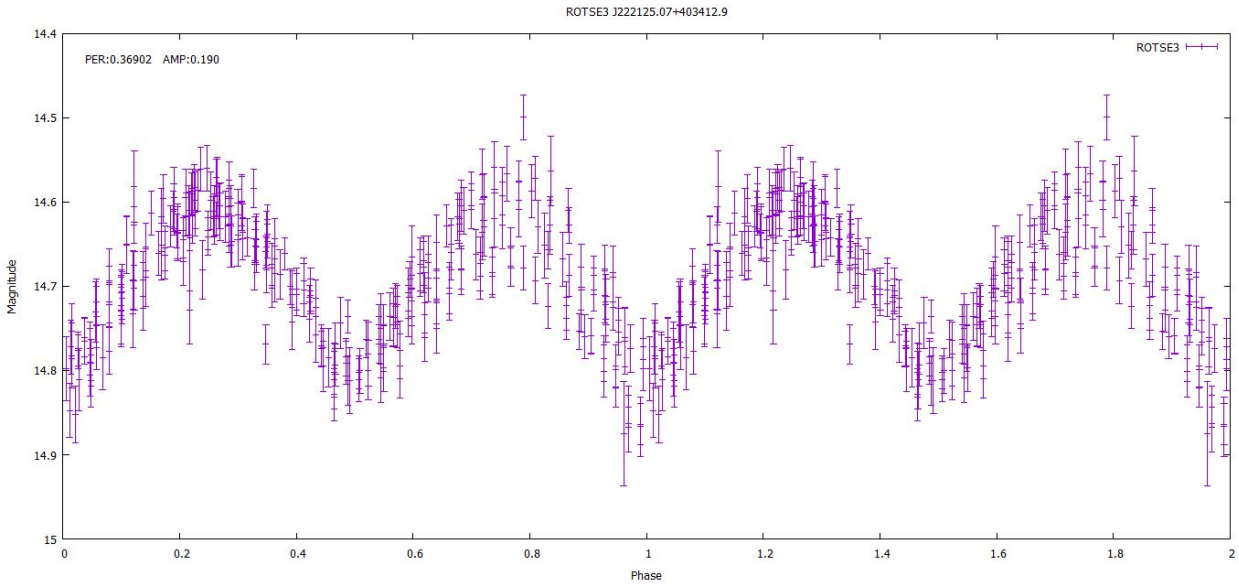

Figure 5: A ROTSE3 discovery that used ROTSE data exclusively.

Name	Constellation	Type	Magnitude Range	Period [Days]
ROTSE1 J000459.91+233315.0	Pegasus	ELL	11.97 - 12.07 (R1)	0.389094
ROTSE1 J000546.47+331545.1	Andromeda	EW	13.15 - 13.38 (R1)	0.358822
ROTSE1 J112206.29+375441.9	Ursa Major	EW	13.46 - 13.61 (R1)	0.296779
ROTSE1 J114708.82+383602.3	Ursa Major	EW	13.21 - 13.32 (R1)	0.27908
ROTSE1 J115159.50+371801.3	Ursa Major	EA	13.16 - 13.45 (R1)	0.518288
ROTSE1 J115939.37+432236.3	Ursa Major	EW	14.25 - 14.70 (R1)	0.417234
ROTSE1 J232708.22+371216.9	Andromeda	HADS	12.84 - 12.99 (R1)	0.084457
ROTSE3 J222125.07+403412.9	Lacerta	EW	14.61 - 14.80 (R1)	0.36902
ROTSE3 J222210.88+404033.4	Lacerta	EW	15.31 - 15.67 (R1)	0.371922
NSV 19084	Ursa Major	RRAB	11.32 - 11.47 (V)	0.689474
ROTSE1 J000323.73+352856.9	Andromeda	EW	12.85 - 13.06 (R1)	0.3943
ROTSE1 J000349.50+315316.0	Pegasus	EW	12.63 - 12.78 (R1)	0.43808
ROTSE1 J000613.55+362658.0	Andromeda	EW	13.09 - 13.28 (R1)	0.413161
ROTSE1 J000755.84+333920.2	Andromeda	EW	12.42 - 12.61 (R1)	0.319604
ROTSE1 J002542.98+310715.1	Andromeda	EB	12.86 - 13.12 (R1)	0.613404
ROTSE1 J232605.82+233719.5	Pegasus	EB	12.94 - 13.17 (V)	0.700826
ROTSE1 J232049.49+250633.7	Pegasus	EW	13.25 - 13.38 (R1)	0.38081
ROTSE1 J232953.24+263620.5	Pegasus	EW	12.78 - 13.07 (R1)	0.3019
ROTSE3 J172014.15+352919.1	Hercules	EW	12.21 - 12.40 (R1)	0.455322
ROTSE3 J221532.62+402235.1	Lacerta	RRAB	14.40 - 15.20 (R1)	0.489555
ROTSE3 J221545.32+395017.9	Lacerta	EW	13.03 - 13.60 (R1)	0.328687
ROTSE3 J221557.53+405956.3	Lacerta	EW	15.56 - 15.91 (R1)	0.264
ROTSE3 J221604.18+404715.5	Lacerta	EW	10.63 - 10.79 (R1)	0.477485
ROTSE3 J221822.13+400218.0	Lacerta	EW	14.15 - 14.37 (R1)	0.40805
ROTSE3 J221904.59+395132.3	Lacerta	EW	16.35 - 16.70 (R1)	0.302588
ROTSE3 J222027.50+395316.8	Lacerta	EW	15.92 - 16.23 (R1)	0.331788

Table 1: ROTSE–I and ROTSE–III Variable Star Discoveries. The separating line divides the table into two groups: first those listed with the author as primary discoverer, and the second group with updates or those with the author listed as secondary discoverer.

Vestrand, T., and Wren, J. An untriggered search for optical bursts. *The Astrophysical Journal 577*, 2 (2002), 845.

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[6] Otero, S., Watson, C., and Wils, P. Variable star type designations in VSX. *VSX*.

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[8] Rykoff, E. S., and Smith, D. Components and Operation of the ROTSE-III Telescope System. *University of Michigan, Ann Arbor* (2003).

[9] USNO. Julian date converter.

[10] Winkler, G. Modified julian date.

Pathways Through Care

Decision–Making and Treatment Dropout in Early Psychosis

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Young people who are hospitalized after their first episode of psychosis have unique insights and experiences with the mental health care system. Many of these young people will choose not to continue with mental health care treatment after this experience. Current research does not provide an adequate explanation for this. Using ethnographic research methods, study participants are interviewed and observed four times throughout their post–hospitalization journey to elicit treatment opinions and decisions. This study is ongoing, with plans to publish in late 2016. Results from September 2015 include 9 finished study participants, with 6 continuing mental health care treatment and 3 discontinuing mental health care treatment.

1 Introduction

The Pathways Through Care research project is an ongoing research study to gather knowledge about treatment decisions made by young people during the initial period following a first episode of psychosis. Many people in this situation deny treatment, and current research does not provide an adequate explanation for this. Although the thought of mental health care used to bring about asylums and electroshock therapy, mental health care in today's world is an ever-evolving field that ideally incorporates tools such as therapy, pharmaceuticals, and residential treatment programs into management programs on a case–by–case basis. In reality, mental health care is not perfect; the demand for quality care seems to outnumber the supply in most cases, especially in lower–income populations. Each individual has his or her own life experiences and opinions of health care, but is there a common experience in the initial interface with psychiatric treatment that is causing large numbers of people to discontinue mental health care? The motivation for the research is to gain insight into the reasons why patients either follow or leave treatment. The long–term goal is to create knowledge about systematic changes needed to keep mentally distressed patients involved in care processes.

2 Methods

Using ethnographic research methods, such as interviews and participant observation, data was gathered from patients who had been identified by mental health professionals in Green Oaks Hospitals, a part of the Medical City hospital system, as recently experiencing their first episode of psychosis, as well as their key supporters (as identified by the patient). These individuals were tracked through the first stages of treatment for mental health issues. Interviews were conducted with the research participants (one during initial diagnosis and three during the weeks following) to elicit their treatment experiences and options, with a set list of questions including questions such as "Do you think the mental health care system is a resource or a burden?" and "How would you describe your experience with the mental health care system?" These interviews were audio recorded and transcribed. Field notes were taken about the interactions and activities that transpired during the research process. The population of the study will ultimately result in two groups of approximately 12 patients: one group of patients who continued with treatment and one group of patients who did not continue treatment. All patients are within the age range of 18–30.

3 Results

As this study is ongoing, definitive results cannot be given at this time. The study is planned to conclude with disclosure of findings under Dr. Myers in late 2016. The focus of this summer work was to continue collecting data. As of September 2015, 9 participants

*Mentor: Dr. Neely Myers, Assistant Professor of Anthropology, Dedman College, SMU

have completed the study. 6 of those participants followed up with treatment and 3 did not choose to continue with treatment. While conducting this research, we discovered common patterns and trends within the system. Most of our subjects often come in with loved ones or local authorities to Green Oaks and are checked in against their will. Upon arrival, some patients are sedated and wake up in a foreign room, given very little information about their treatment team or what medications they are currently given. Subjects reported this as a common difficulty across different hospitals in the DFW area; it seems that while our subjects are under the care of mental health professionals, they are not always fully aware of their treatment plan or are too heavily sedated to remember. Patients are not often held for long periods of time in Green Oaks, and they are either released to continue with an outpatient program or, for those who need more care, sent to another hospital, quite often Terrell State Hospital. Terrell is regarded as a last–resort stop for many patients. Those who refuse to take their medication are sent to Terrell, where we they either begin to take their medication (how this occurs has not been explained to us) or stay until their insurance runs out and they are discharged. Insurance was an interesting subject within these hospitals: in general, those with better, often private insurance got to stay longer in Green Oaks, and those with public or less comprehensive insurance were quickly transferred to Terrell. The Affordable Care Act has not seem to make a big difference in our patients' lives, and the hospitals seem slow to adapt to these new policy changes. Many of our patients disliked their stay in Terrell; others viewed Terrell as what they needed to begin to deal with their mental distress. In fact, it seemed that most of our patients looked upon their experience with the mental health care system as a burden: either the patient felt no benefit from their experience, or they wished to never be involved with the system again. They seemed to crave normalcy. Among a few of our patients, the actual diagnosis of a mental health problem or disorder was ignored; patients blamed their psychosis on things such as low iron levels in the blood, irregular electric shocks originating from their heart, or drug use. Drug use among the patients was common, either as a habit or as an outlet used to explain the symptoms of their mental distress.

4 Contributions

My individual contribution to the team was often connected to my closeness in age to the study participants. I visited patients in hospitals to provide a peer for casual conversation to help the patients become accustomed to our research team, as most patients did not recall meeting our team in Green Oaks. Meeting someone of the same age seemed to help the patients become more comfortable with talking to us while conducting the actual interview; having someone else who understands the popular culture and social expectations on today's young adults can encourage a patient to open up more about their personal life. As a team member, I conducted interviews with my team, as a two–person interview team is required during interviews outside of mental hospitals for safety. I also transcribed baseline interviews with new patients for general team usage, to ensure quick and confidential information transfer.

5 Future Improvements

Mental health research, and furthermore research of the brain, is fairly new in comparison to other sciences. When researching mental health in our modern age, it is important to view treatment holistically. Treatment is no longer described as simply pharmaceuticals; rather it is a comprehensive system including therapists, behavioral changes, and sometimes alternative care such as religion or homeopathic remedies, and in order to thoroughly understand how mental health is being treated, all aspects of treatment must be accounted for. In our specific research, we focus more on the institutionalized system, but we found that some of our patients relied more on religion as a healing power, more so than any services offered in traditional health care. While conducting research in the same vein as Dr. Myers's project, it would be beneficial to take a stratified population, even more so than our age restrictions. For example, specifically studying immigrant's experience with the mental health system could be beneficial. An interesting build upon this study would be to recreate the same study, but to only interview patients who had multiple experiences with the mental health care system. The opinions of these kinds of patients could be invaluable, since they would have a greater knowledge of the system, and how to work it to their advantage. Our patients are all new to mental health care and are experiencing this system for the first time.

6 Reflection

Through my involvement in this study, I began to see diagnosis and treatment through a patient's eyes. I have found that even though I am not a doctor, I

already put myself in the shoes of a medical professional when looking at diagnoses and treatment decisions. As a biology major, I tend to think of disease as a physical ailment that is caused by a certain physiological malfunctions and can be fixed through pharmaceuticals, surgery, or therapy. Patients have a different view, which often does not include looking at the science behind an illness. By working on this study from an anthropological viewpoint, I was able to see more of the human side of medicine. While talking to patients, I was able to hear first–hand accounts of the experiences on the other, more human, side of treatment and began to understand why a patient would choose not to take their medicine or to refuse to cooperate with a therapist. Through my pre–medical student's eyes, it seemed that refusing traditional mental health care for alternative treatments or simply refusing any kind of care is an incorrect choice that would only be detrimental to a patient's condition. Patients within this study opened my eyes and allowed me to recognize why the prescribed treatment is not always right for them and why they choose to deny this treatment. Many patients voiced concerns over a lack of information transferred to them from the doctor and a feeling of inattention because their doctors were overwhelmed by the number of patients they see everyday. During my future as a medical student and doctor, I can help to ease those sorts of concerns and address the needs of my patients now that I have knowledge of this consensus among patients. By gaining this patient understanding as an undergraduate, in the future I will approach my learning of medicine from the standpoint of both a doctor and a patient. I will be able to more clearly approach diagnoses and treatments from a patient interpretation, which can help me create a dialogue and understanding with my patients. Participating as a Summer Research Assistant in Dr. Myers lab allowed me to expand on fundamental knowledge required to create the best possible doctor–patient relationships in the future.

The role of BAMBI and GEM in Neuronal Apoptosis

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Abstract

Neurodegeneration poses a serious threat to human beings, placing a substantial burden on health care providers as well as patients and their families. Because these diseases currently have no effective treatments or cures, it is imperative to identify molecules involved with regulated neuronal death. In patients with Parkinson's, Alzheimer's, and Huntington's diseases, neurons undergo a type of programmed cell death called apoptosis. This mechanism of death requires the cells to produce new proteins that initiate cell suicide and deconstruct it from within. The D'Mello Lab previously discovered that a transcription factor, FOXP1, is protective in neurons when over expressed. The next logical step in studying FOXP1's mechanism of protection was to investigate specifically which genes were regulated by its activity. RNA-seq experiments revealed a list of genes which showed differential expression while FOXP1 levels were elevated in cells [1]. I chose two of these genes, *BAMBI* and *GEM*, to study in the D'Mello Lab's cell death models. Using molecular biological techniques, I found that *BAMBI* and *GEM* both undergo changes in expression while cells are dying. To investigate what this meant for cell death, I proceeded to express *BAMBI* in neurons and study *GEM*'s expression in aging rats. According to the Allen Brain Atlas [4], *GEM* is barely expressed in the brain. We therefore ought to explain why its expression was detected in the RNA-seq and why we were able to detect it in cerebellar granule neurons by observing its expression in rats of different ages. Ultimately, I discovered that BAMBI is toxic to neurons when overexpressed and that GEM's expression reduces as rats age, dropping dramatically when they reach one month old. These data indicate that BAMBI's expression may be important for regulating apoptosis and that GEM may play a role in neural development.

1 Background and Significance

Parkinson's, Alzheimer's, and Huntington's diseases are all characterized by uncontrolled neuronal apoptosis, or programmed cell death. Why these cells destroy themselves in neurodegenerative disease is poorly understood, so no cure or treatment exists to restrain or reverse the loss of neurons. For this reason, the aforementioned diseases pose a serious threat to people on a medical, social, and economic level. Constantly battling the symptoms of neurodegeneration can only take a person so far without a solution to what causes them, putting massive strain on families and budgets. Identifying molecules that can protect neurons from death is therefore critically important to understanding not only how these diseases operate and develop, but also how they can be prevented. This project focuses on genes regulated by FOXP1, a transcription factor belonging to the forkhead box protein family. FOXP1 is most highly expressed in the striatum and cortex, where it may play an important role in maintaining healthy neurons and protecting them from degeneration. Mutations in FOXP1 have also been implicated in disorders such as autism [1]. Huntington's disease (HD) is caused by a mutation in the gene encoding the huntingtin protein resulting in a pathogenic isoform (mut-Htt) that has an expanded stretch of polyglutamine repeats. In HD, the expression of FOXP1 is reduced in the aforementioned brain regions, indicating that its presence in healthy brains is important for the survival of neurons. Consistent with this hypothesis, increasing FOXP1 expression in cultured cortical neurons protects them from mutant huntingtin (mut-HTT) while reducing its expression induces death in otherwise healthy neurons. My overall goal is to examine whether genes that have previously been identified to be upregulated or downregulated in mice lacking FOXP1 are targets of FOXP1 in its neuroprotective action. In the long-term, identifying molecules integral to programmed cell death

will further our understanding of Huntington's Disease and potentially lead to more effective treatment options.

2 Methods and Expected Results

The D'Mello Lab proposes that FOXP1 acts by reducing expression of genes that mediate mut-Htt toxicity or upregulating genes that block toxicity. Dr. Genevieve Konopka's lab at UTSW recently generated mice that lack FOXP1 in the brain and identified alterations in the expression of a large number of genes in the brains of these FOXP1–deficient mice. The expressions were quantified using RNA–seq, a method prone to delivering false positives. This data set of alternatively expressed genes was shared with our lab. Among the genes whose expression is supposedly altered are several which are associated with the regulation of cell survival and death. I studied six of these genes: *CDKN1*, *PDE8B*, *BAMBI*, *TGFB1*, *GEM*, and *GPX3*.

Our lab uses several models for determining whether or not genes are involved in apoptosis. The one most relevant to the rest of this paper is our High Potassium, Low Potassium (HK/LK) model for neuronal development. During development, the brain produces twice as many neurons as exist in the adult brain. While it is not fully understood why such overproduction occurs, a cell's electrical activity does seem to play a role in determining which ones survive and which ones undergo apoptosis. By incubating cerebellar granule neurons (CGNs) in media containing high potassium concentration (125 mM), we force them to depolarize and remain electrically active. In contrast, those cells incubated in low–potassium media (5 mM) are not as electrically active and thus undergo apoptosis. By assessing which genes are turned on or off at different times, we can then hypothesize which ones are involved in survival or death. Generally, three hours and six hours are used for time points because the cells are already committed to apoptosis beyond six hours, which means late expression changes have no bearing on the eventual death of the cell.

2.1 RT-PCR

In order to verify whether FOXP1 really up- or downregulates these six genes, I used a technique called reverse transcriptase polymerase chain reaction (RT–PCR), in which mature mRNA is transcribed into cDNA, which is then amplified with *Taq* polymerase. The amplified product was run on a 1% agarose gel via electrophoresis in order to visualize the changes in gene expression. Underlying this procedure is the idea that if a gene is being more highly expressed, there will be more mRNA transcripts of it to begin with, which leads to more cDNA for that gene and eventually a darker band of amplified PCR product. With this in mind, I took mRNA isolated from cells overexpressing *FOXP1* and cells overexpressing a control molecule, Green Fluorescent Protein (GFP). Genes upregulated by FoxP1 yield bands that are much darker than the GFP counterpart, and those that are downregulated exhibit the opposite effect. Surprisingly, none of the genes I studied showed remarkable upregulation or downregulation in those cells overexpressing *FOXP1*. Two of them, however, BAMBI and GEM, showed profound changes in the High K+/Low K+ model (Figure 1), so we decided to study them further.

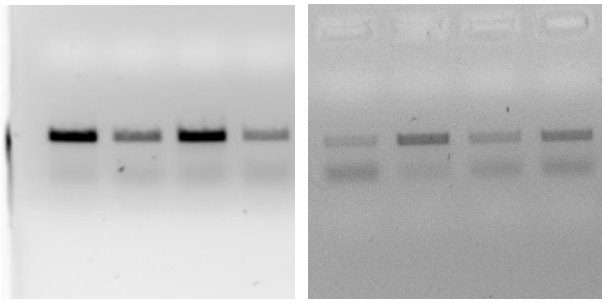


Figure 1: The lanes for each sample are 3 hr High K^+, 3 hr Low K^+, 6 hr HK, and 6 hr LK. BAMBI (left) and GEM (right) showed opposite expression patterns, being upregulated in high potassium and low potassium conditions, respectively.

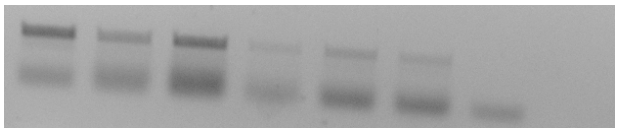
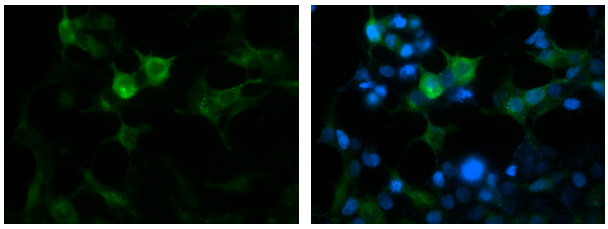


Figure 2: From left to right, the bands represent GEM expression in rats of increasing age. The lanes are as follows: HK CGN lysate as positive control, Embryonic Day 17, Postnatal Day 7, 1 month, 6 months, 12 months, negative control. The fourth lane (one month) shows a dramatic drop in expression compared to the preceding lane of a P7 rat, implying that some developmental switch shuts down gene expression at this point.

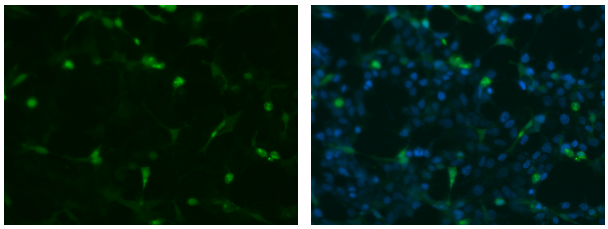
I also examined *GEM*'s expression in rats from embryonic day 17 to one year old. Figure 2 shows that expression drops dramatically after one month in the rat brain, meaning that the gene is really only expressed in very young animals.

2.2 BAMBI

The protein BAMBI (BMP and activin membrane-bound inhibitor) is a membrane–bound negative regulator of the TGF-β superfamily. TGF-β family members are involved in many cellular functions and have been shown to be downregulated in tumor cells [10]. Typically, their signaling works as follows: a molecule of TGF-β binds to the receptor domain of a type 1 receptor kinase, which then binds to and phosphorylates a type 2 receptor kinase and forms the active ligand–receptor complex. A protein kinase cascade then transduces the appropriate signal to the cell, depending on which family member and which receptors are involved. BAMBI, though structurally similar to a type 1 receptor kinase, lacks the intracellular kinase domain [5]. Thus, when it binds its ligand, the signal stops at the membrane. BAMBI has been found to be overexpressed in human osteosarcoma cells [10] as well as ovarian cancer cells [7], indicating that it has powerfully proliferative effects. Neurons, which are post–mitotic cells, generally undergo apoptosis in response to reentering the cell cycle [8]. This information indicates that *BAMBI* overexpression would be toxic to neurons. According to the RT-PCR results, however, BAMBI should be protective as it showed profound upregulation in both 3–hour High K^+ and 6–hour High K^+. The only way to determine which hypothesis is accurate was to overexpress it in neurons.



(a) BAMBI in 293T GFP–tagged



(b) GEM in 293T CFP–tagged

Figure 3: Nuclei were stained with DAPI (1:10,000 dilution) and the two proteins were each tagged with an autofluorescent molecule: GFP (Green Fluorescent Protein) for BAMBI and CFP (Cyan Fluorescent Protein) for GEM. Fortunately, the green filter on our fluorescent microscope also detects CFP.

2.3 GEM

GEM is a member of the RGK subfamily of Ras–related G–proteins. Unlike its heterotrimeric cousins, GEM exists as a monomer within the cell, influencing cytoskeletal arrangements and negatively regulating calcium channels. Structurally, it has a Ras–like core which houses its GTPase domain in addition to N- and C-terminal extensions which bind calmodulin and 14-3-3 [2, 3]. Because of its nuclear import signal, GEM localizes in the nucleus unless it becomes bound to calmodulin in the cytosol. In this way, a high intracellular Ca^{2+} concentration enables calmodulin to retain GEM in the cytosol, where it plays an active role in calcium signaling. For example, if a cell experiences increased levels of Ca^{2+} in the cytosol, GEM will be held outside of the nucleus and thus be able to bind the β subunit of voltage–gated L–type calcium channels (VGCC). It is believed that GEM prevents the subunit from successfully reaching the plasma membrane, effectively disabling the channel [2]. Neurons rely on VGCCs in order to prolong their action potentials, and calcium has been shown to play an important role in both long and short term potentiation at synapses [6]. Based on my RT-PCR results, I expected that GEM would prove toxic to neurons, a hypothesis supported by its role in removing calcium channels vital for neuronal function.

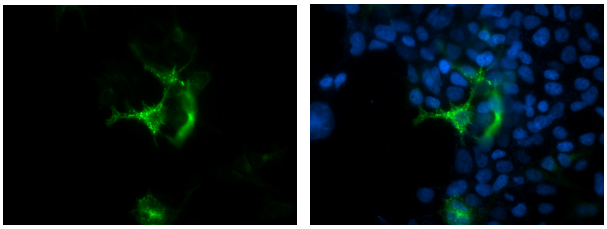
2.4 Plasmid Generation

Using the Accuprime PCR system (Invitrogen), I amplified the full coding region of *BAMBI* with *Hin*dIII and *Sac*II restriction sites on either end. I then digested the amplified DNA and an eGFP N-1 vector with both *Hin*dIII and *Sac*II restriction enzymes, ligating the products together to form the completed expression vector with *BAMBI* inserted. After transforming the plasmid into bacteria and growing it up, it was sent to Retrogen for sequencing to ensure that no mutations occurred during the cloning process.

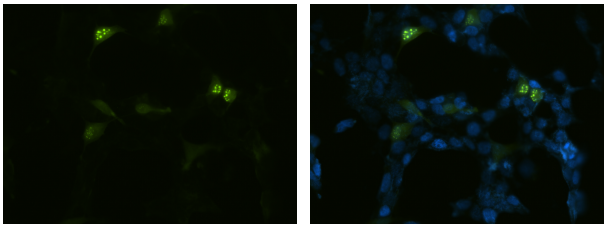
Issues arose with GEM's cloning primers, so we purchased a *GEM* plasmid from Addgene [9]. Both plasmids were verified by Retrogen.

2.5 Cell Culture

In order to confirm that the genes were expressing well, I transfected them into cell lines and assessed them through fluorescent microscopy as well as Western Blot analysis. First, I transfected both *GEM* and *BAMBI* in 293T Human Embryonic Kidney cells (Fig-

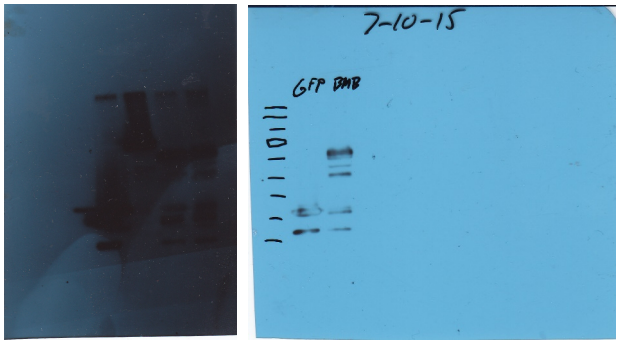


(a) BAMBI in HT-22 GFP–tagged



(b) GEM in HT-22 CFP–tagged

Figure 4: Nuclei were stained with DAPI (1:10,000 dilution) and the two proteins were each tagged with an autofluorescent molecule: GFP (Green Fluorescent Protein) for BAMBI and CFP (Cyan Fluorescent Protein) for GEM. Fortunately, the green filter on our fluorescent microscope also detects CFP.



(a) The lanes are as follows: GFP, GEM, BAMBI (lysed in Cell Lysis Buffer), BAMBI (lysed in RIPA buffer).

(b) The lanes are GFP and BAMBI (both lysed in RIPA).

Figure 5: These Western Blots show that proteins of the proper size were being produced, albeit a messy blot for GEM.

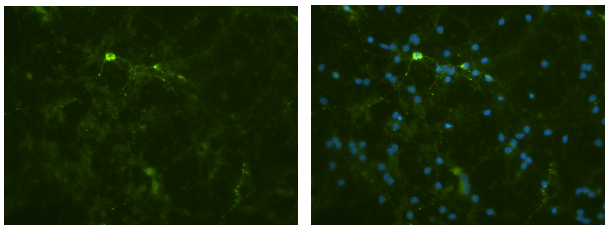


Figure 6: Like with the cell line microscopy, the nuclei were stained with DAPI (1:10,000 dilution) and BAMBI was tagged with GFP. A single neuron was transfected in this field as the transfection rate for CGNs is less than one percent of the population.

ure 3) then again in HT-22 neuronal blastoma cells (Figure 4). This allowed me to study their localizations within the cells and ensure that the vector produced a fluorescent product different than GFP by itself. Simultaneously, I transfected a large number of 293Ts for use in Western Blots. I lysed the cells in RIPA buffer as well as Cell Lysis Buffer (Cell Signaling), then ran them on 10% SDS-PAGE gels and transferred them to PVDF membranes for analysis with x–ray film using the ECL reagent. The Western Blots confirmed that the expressed protein was of the expected size (Figure 5).

The microscopy showed several interesting things about each protein. *BAMBI* expressed well in both cell lines and exhibited a unique punctate pattern across the cells. Generally speaking, large dots would indicate some kind of protein aggregate, although they could also represent lipid rafts floating in the membrane, serving as docking sites for BAMBI, keeping many BAMBI molecules together to facilitate dimerization. Exactly what those spots are has yet to be elucidated. GEM likewise showed a unique expression pattern: large collections of the protein appeared in the nucleus. Nucleolar proteins tend to show a similar pattern, but they number from one to five spots, not six or more. As with the BAMBI spots, the identity of the GEM spots is unknown at the moment. They could be evidence that GEM is sequestered inside the nucleus, waiting for intracellular calcium levels to rise enough for calmodulin to retain it in the cytoplasm. Supporting this idea, the cell in the lower left quadrant of "GEM HT-22 CFP" shows both nucleolar spots and cytoplasmic localizations.

After verifying the *BAMBI* plasmid in these other cell lines, I transfected it into cerebellar granule neurons, shown in Figure 6. Just as in both 293T and HT-22 cells, *BAMBI* exhibited a spotted phenotype in CGNs. Both healthy and unhealthy neurons contain the spots, so it is unlikely that they are detrimental to cell survival.

2.6 Survival Assay

Twenty–four hours after transfecting CGNs with either *BAMBI* or *GEM*, I treated the cells with high potassium media and low potassium media in addition to treating untransfected cells. After waiting an additional 24 hours, I fixed the cells onto cover slips,

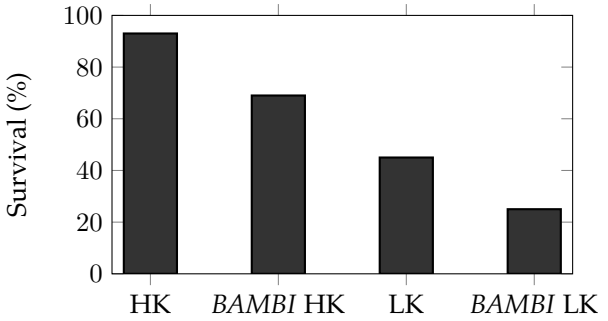


Figure 7: Untransfected HK cells showed very little death with 93% viability, whereas LK only exhibited 45% survival. BAMBI showed less survival in both conditions with 69% in HK and 26% in LK.

then counted living and dead cells in the two conditions. I counted all conditions and tabulated the results, shown in Figure 7.

3 Conclusion

BAMBI is toxic when overexpressed in cerebellar granule neurons. More trials are needed to make these results statistically significant, but with initial results of a twenty percent drop in viability, it looks like this protein may be integral in neuronal apoptosis. Going forward, I plan to suppress BAMBI in both high potassium and low potassium to see if that has the opposite effect in addition to troubleshooting the GEM plasmid to achieve expression in CGNs. If BAMBI is important to causing apoptosis, then suppressing it should rescue neurons from toxicity. Testing both of these genes in disease models would also improve their relevance to the medical community, however GEM's expression data would imply that it is not functional in disease states. Because GEM's expression drops dramatically at one month in the rat brain, it is reasonable to think that its role is purely developmental and thus not pertinent to disease models. Therefore, GEM may no longer be on the table for research in this lab.

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Testing Seymour Lipset's Theory in "Some Social Requisites of Democracy"

Democratization Without Modernization in India

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1 Introduction

In "Some Social Requisites of Democracy: Economic Development and Political Legitimacy", Seymour Lipset argued that "economic development" and governmental "legitimacy" were important systemic social factors that contributed to the transition to democracy and the consolidation of democracy [1959, 71]. Lipset's theory reasoned that to lay the social groundwork for democratization, societies first needed to undergo social and economic development, according to Ryan Kennedy [2010, 785]. Barbara Geddes maintained that Lipset's argument about social and economic development preceding democratization was so influential that it has become a widely held position that democratization is more likely to occur in economically and socially advanced countries [1999, 117]. In the absence of economic and social development, this paper argues that the development of legitimate institutions and a democratic political culture, both led by elites favoring democracy, can help to explain why some countries democratize. Before turning to the substance of the positions advocated here, it is important to remember Larry Diamond's observation that Lipset's theory about the relationship between economic and political development has served as the basis for much of the democratization scholarship that followed Lipset [1992, 450].

2 Literature Review

Daron Acemoglu et al. asserted there was weak evidence to support a causal relationship between income and democratization [2009, 1057], yet Ross Burkhart and Michael Lewis-Beck concluded that there probably is a causal relationship between economic development and democratization [1994, 907]. Zehra Arat found that in the countries he studied only eight out of one-hundred and twenty countries exhibited a correlation between economic gains and democratic gains [1988, 30], and reversing the variables David Leblang claimed that there was a correlation between democracy and economic growth [1997, 462]. Adam Przeworski and Fernando Limongi contended that the initial transition to democracy is not dependent on a country's level of wealth [1997, 177], but with a more democratically developed country economic development helped the continuation of democratization, according to Axel Hadenius and Jan Teorell [2005, 103].

3 Research Question

Democratization in India serves as a useful test case for some of the disagreements that exist in the academic literature about whether and what cultural, economic, institutional, and social conditions cause or correlate with democratization. In terms of the economic and social criteria used to ascertain modernization, Lipset proposed that four variables—education, industrialization, urbanization, and wealth—can lead to a conducive environment for democratization [Lipset, 1959, 75]. Education [Kingdon, 2007, 169], industrialization [Mazumdar, 2011, 42], urbanization [Swerts et al., 2014, 44], and wealth [Ness, 2006, 139]—all four of these indicators of modernization show that India is underdeveloped. Despite this economic and social underdevelopment, Alistair McMillan stated that Indian democracy is durable and consolidated [2008, 734]. India's seemingly contradictory possession of an underdeveloped economy and a consolidated democracy raises the question: How can Lipset's theory account for successful democratization in an economically and socially underdeveloped country?

4 Independent Variables and Initial Justification

Writing in response to Lipset's propositions about the positive relationship between economic and social development and democratization, Deane Neubauer held that in the democratization process political culture was as important as the Lipset's variables of economic and social conditions [1967, 1008]. In creating democratic mores, political elites play a crucial role [Stevens et al., 2006, 607]. The two proceeding observations apply to India because: (1) The Indian National Congress (INC) was composed of elites before the transition to democracy [Mehta, 2012, 537], and (2) the INC helped to usher in democratization in India [Reddy, 2005, 272]. Consequently, it is appropriate to study India's democratization in terms of political elites and state institutions. As for the role of legitimate institutions in the democratization process, Adam Przeworski contended that consolidation of democracy relies upon the effectiveness of political systems [2000, 129]. Institutional effectiveness leading to democratization applies to India because: (1) In their colonies the British created strong capitalist institutions [Olsson, 2009, 540], and (2) the British colonization of India created an effective and nation-wide civil service [Malik et al., 2008, 19]. To determine the influence of political elites and institutions on democratization in India, this paper will employ Michael Sodaro's variables of "elites committed to democracy" and "state institutions" [2004, 223–4].

5 Thesis and Research Statement of Purpose

In using these standards of measurement to determine the status of the three independent variables in India, the primary purpose of this paper is to understand Lipset's theory, not merely democratization in India. Lipset's theory does not predict successful democratization with economically and socially underdeveloped countries because his theory does not account for the disproportionate roles motivated elites and institutional factors can play in the democratization process.

6 Counterargument

In theory and in terms of India, a counterargument could be made for why each of the independent variables researched in this paper—political elites committed to democracy and state institutions—undermined democratization in India. Inequality tends to lead to autocracy, but equality supports democracy [Ansell and Samuels, 2010, 1545]. The observation about inequality positively correlating with autocracy relates to the variable of political elites committed to democracy in India because: (1) There is long-term economic inequality in India [Azam, 2009, 545]; (2) commented that elites in India have been displeased at their decline in relative power due to democratic government [Nandy, 1989, 11]; (3) elites tend to leverage their influence in government to protect their economic interests [Sloan, 1984, 96–8]; and (4) during periods of scarce resources elites reliably protect their own interests at the expense of other social groups [Gurr, 1985, 60–61]. Consequently, political elites in India had both the economic incentives and political influence to block democratization.

Finally, in terms of the variable of state institutions, Robert Lieberman commented that by the nature of their uniformity and incrementalism institutions do not foster institutional change easily [2002, 700]. The United Kingdom's colonial administration never permitted Indians to fully govern their own territories until after independence [Subrahmanyam, 2006, 91]. Consequently, the shift from colonial rule to independence in India was something for which India's nascent independent state institutions were unprepared.

7 Justification and Operationalization

Laying out the theoretical justification for why elites would commit to democratization, Daron Acemoglu and James Robinson observed that in times of prerevolutionary social unrest elites prefer and promise economic redistribution in a democracy as opposed to outright revolution [2000, 683–4]. A democratic or quasi-democratic form of government is also in the interests of the elites in the new dispensation because a democracy will serve as a forum for resolution among national elites [Higley and Burton, 1989, 19]. Once the democratic government is established, David Truman commented that elites have a vested interest in seeing the democracy continue because their perquisites are connected with the new democratic political order [1959, 489]. Patrick Heller asserted that India's elites support of democracy is also founded on the patronage they receive from the democratic system [2000, 485].

To operationalize and measure the variable of "elites committed to democracy" this paper will use

the following assessments: (1) "adult political socialization [of elites]" from Sullivan et al. [1993, 59] and (2) "foreign education" from [Spilimbergo, 2009, 528]. The "adult political socialization [of elites]" evaluative criteria is justified by Gita Subrahmanyam's observation about Indian elites receiving greater governing experience under British indirect rule than other colonial possessions of the United Kingdom [2006, 106]. Evidence to substantiate this claim includes: (1) carryover of Indians in colonial executive roles in the independent Indian government, (2) level of exposure to British democratic values, and (3) Indian elites embracing democratic values.

The use of "foreign education" as the second social indicator is justified from Yogendra Singh's comment about the predominance of a British education among many Indian political leaders [2012, 152]. Evidence to substantiate this claim includes: (1) number of Indian students studying abroad, (2) effect of British education on Indian political views, and (3) changed policies on the stratification of society through the Indian caste system.

The measurement of "national integration" is justified on the basis of Merera Gudina's observation about the crucial role elites can play in leading nationalist movements [2004, 28]. Evidence to substantiate this claim includes: (1) elites forming alliances in the Indian Independence Movement across ethnic, religious and linguistic boundaries, (2) elites shaping the policies of the INC, and (3) the level of organizational discipline and cohesiveness across the Indian nationalist movement.

As for the justification for arguing for a positive relationship between effective state institutions and democratization, John Higley and Michael Burton noted that the effectiveness of state institutions actually interrelates with the independent variable of elites committed to democracy because. Elites seek to reduce inter-elite conflict by institutionalizing conflicts in government, and this in turn leads to democratization, as Higley and Burton observed [1998, 99]. As effective institutions relate to India, Atul Kohli noted that after independence from the British the nation of India still benefitted from the effective civil service that was established during colonial times [2010, 1273]. As for another possible motive and method for elites to create effective and stable institutions, Anne Sa'Adah held that the rule of law was a means by which the existing social order could be perpetuated [2006, 306]. In addition, other researchers have found that the rule of law is a necessary institutional and cultural element of democratization [Beal and Graham, 2014, 313]. Not only do effective state institutions contribute to democratization, but the motives for elites to establish effective state institutions are: (1) Elites want to minimize major friction within their social class by having the government serve as a forum for their interests, and (2) the rule of law and by extension effective state institutions perpetuates the social standing of elites in society.

To operationalize Sodaro's independent variable of "state institutions" Indian institutions will be measured in the following manner: (1) The role of Indian civil service in nation building, (2) effectiveness of India's legal system, and (3) perceived popular legitimacy of India's legal system.

In accessing elite support for democracy in India, this paper will demonstrate that: (1) Elites possessed the power to effectuate democratization; (2) elites held democratic values; (3) the social structures that spread democratic values; (4) the effects of Western education on democratic values in India; (5) Indian elites formed socially cross-cutting alliances, (6) the democratizing effects of the INC in post-colonial India, (7) the level of organizational discipline across the INC, and (8) how the democratic values of the Independence Movement were carried forward by political and bureaucratic figures in the democratic consolidation period.

8 Evidence Demonstrating the Independent Variable of "Elites Committed to Democracy"

For the first evaluative criterion, Indian elites embracing democratic values, this paper will first show evidence supporting the claim that Indian elites were prepared to democratize India. According to Leela Fernandes in the years preceding Indian independence, Western educated Indian elites had accumulated the power to transform Indian society because: (1) Indian elites held a sizable number of posts within municipal offices and as advisors to the colonial government, and (2) these Indian elites also dominated Indian political discourse [2006, 15]. As for Indian elites' support of democratization, Thomas Hansen characterized the leaders of the Indian Independence Movement as generally supportive of liberalism [1999, 40]. Hansen added the British instituted an intentional strategy to negotiate with and communicate to the Indian elites, rather than the lower classes, on issues of modernizing India [1999, 32, 38]. The relationship between an elite class groomed to govern by British colonial authorities and that country's subsequent democratization is supported by John Higley's and Michael Burton's findings about India and other former British colonies [1998, 99]. Myron Weiner proposed that not

only were the values secularism and democracy held disproportionately among Indian elites (including leaders of the INC, civil service, and military) in comparison with the lower classes, but these liberal values were institutionalized in the post-independence Indian Constitution [1972, 253]. With both the power and belief to democratize India, Indian elites created a constitutional pre-commitment to democracy in India, despite the weakness of popular support for democratic values at independence.

The next evaluative criterion, level of exposure to British democratic values, helps to further explain why Indian elites held democratic values. Ranbir Vohra argued that during British colonial rule the British, via the education system they established, introduced Indians to "the ideals of free speech, free press, democracy, and participatory government" [2012, 86]. As this paper will later demonstrate, the democratic political culture amongst the elites, that the British education system helped to instill in India, is a crucial cause of why Indian elites favored democracy. During the Independence Era, most of the Indian political leaders in the INC and across the political spectrum were wealthy and educated abroad or at Western-style schools and colleges in India [Malik et al., 2008, 89]. An indirect cause of the growth in enrollment in Western-style and democratizing universities in India was that higher education was a pathway to a more secure socioeconomic status in India [Fernandes, 2006, 22]. As for the ongoing democratizing influence of education in post-Independence India, as Martha Nussbaum maintained there is a widespread belief that the education system should promote the liberal values of the Indian Constitution [2009, 275]. Given the exposure of Indian elites with democratic values and the commitment to those values on the part of the Independence Era leaders, it is important to show that those leaders continued to exercise power after independence.

This paper will use (1) the level of Western education in India and (2) the number of Indian students studying abroad and as another evaluative criteria for whether and why Indian elites supported democracy. Arguing that Western education is a proxy and a possible cause for democratic political culture is justified by Sumit Sarkar's comment: "The British used education as a means of changing the culture of India" [2001, 25]. Ashis Nandy noted that the British began to Westernize the Indian educational system in the 1820s [2006, 285], and in 1944 Syama Mookerjee stated that nearly all of the professors and administrators in higher education in India were Western in that and previous eras [1944, 31–32]. The British motive for educational reform was directly tied in with the need to create a class of Indian agents for the British colony, as Sarkar explained [2001, 26]. Malik et al. hypothesized that an effect of the British established educational system was both the creation of an educated, professional, and urban middle class, and the education system also exposed Indians to the political movements of nationalism [2008, 20].

As for the number of Indian students studying abroad in Britain, the numbers show a growing trend. Hilary Perraton found that from 1880 to 1900 the percentage of students from India studying in Britain's universities grew from approximately one percent to three percent of the undergraduate total student population in Britain, and for the academic years of 1921–2, 1926–7, 1931–2, and 1938–9 India sent the largest number of undergraduate students to Britain of any foreign country [2014, 58].

The next evaluative criterion is whether or not policies on the stratification of society through the Indian caste system changed during the Independence Era and because of the Independence Era's influence. In an example of an elite working to safeguard lower caste members, Ranbir Vohra recounted that due to the direction of Mahatma Ghandi, as a leader of the INC, he struck the "Pune Pact" of 1932, which gave lower caste Indians better electoral representation (2013, 160). In the post-colonial period, constitutional protections for the lower castes was instituted by providing equality before the law regardless of caste affiliation, as Malik et al. observed [2008, 47]. As for how caste affiliations were manipulated in the post-colonial era, Malik et al. went on to write that in the first decades of independence lower castes were heavily influenced to vote for the INC, but as time passed the lower castes eventually became more politically independent [2008, 153]. These policy shifts in India show first an institutional and then an electoral transformation of inter–caste relations.

The last assessment in establishing the presence of the independent variable of "elites committed to democracy" is: The carryover of Indians in colonial executive roles in the independent Indian government. A key figure in India's Independence Movement and then India's prime minister for sixteen years in its first post-colonial government, Jawaharlal Nehru strove to create a democratic country, as Gopal Sarvepellai wrote [1980, 304]. Lloyd Rudolf and Susanne Rudolf noticed that a side-effect of the national status and pride that the Independence Era leaders were held in was that the INC and politicians associated with the Independence Era could claim legitimacy from the Independence Era and therefore its democratic ethos [2001, 130]. In the consolidation period of democratization, Leela Fernandes pointed out that the

bureaucracy and its employees was a source of institutional stability before, during, and decades after independence [2006]. In terms of democratic consolidation the significance of post-independence stability of the Indian bureaucracy lies in the fact that the Indian bureaucracy was more supportive of democracy than India as a whole according to Weiner [1972, 253]. In the same book, Weiner went on to note that office holders during the British era of rule were accorded great deference in the Post-Colonial Era [1972, 263]. With the socialization of democratic values amongst Indian elites being spread by the British educational system, the democratic values of Indian elites helped to both initiate and sustain democratization in India.

Appraising whether or not elites forming alliances in the Indian Independence Movement across ethnic, religious and linguistic boundaries, it appears as if elites did form cross-cutting alliances. In pre-colonial times, there was a tradition of royal patronage being distributed among Hindus and Muslims, regardless of religious affiliation, according to Peter Veer [2006, 137]. In the nineteenth century, the British established the INC to serve as a forum for India's religious and racial groups in order to promote unity, and the INC later transformed itself into a movement for national unity and independence, as Ranbir Vohra noted [2012, 115]. Malik et al. commented that during the struggle against the British for colonial freedom a sense of solidarity developed amongst India's elites, and these elites overlooked issues of ascriptive qualities in order to promote their policy of national unity [2008, 20]. In post–colonial politics, Jeffrey Witsoe noted that within the INC friction among elite groups led to the formation of elite-lower caste alliances [2013, 43].

In evaluating the independent variable of "elites committed to democracy" this paper will evaluate the level of organizational discipline and cohesiveness across the INC. Gandhi reshaped the INC, so that it would go from being a party dominated by Anglicized elites to being a party with mass appeal and popularity, as Ranbir Vohra attested (2013, 89). Weiner reasoned that during the Independence Era the INC survived the intense internal elite versus mass conflicts because of the unifying desire for the British to end their colonial rule of India [1972, 253]. In terms of class conflict management between factions, Jorgen Pedersen wrote that Gandhi forged the INC constituent structure, so that the lower castes in the countryside would not threaten the upper castes [2011, 21]. For an ongoing mechanism of party discipline, Myron Weiner described an internal INC organization, the Congress Parliamentary Board, an institution that resolves disputes within the party [1972, 242–3].

9 Evidence Demonstrating the Independent Variable of "State Institutions"

To ascertain the presence or absence of the independent variable of democratic "state institutions", this paper will examine the following issues: (1) The impact of the Indian Civil Service (ICS), (2) the effectiveness of India's legal system, and (3) the legitimacy of India's legal system.

For the evaluative criterion of the role of ICS on nation building, the ICS is apparently large and professional. Ranbir Vohra described the ICS as seeing itself in a privileged position in society [2012, 89]. Kohli observed that the ICS consistently provides effective government services, and the Indian government is also supported by an effective military [2010, 9]. A force for national unity, the Indian ICS' effectiveness in the administration of justice helps to support the rule of law, according to Weiner [1972, 278–9]. As a respected institution, the ICS is important as a nationwide enforcer of the rule of law in India.

In evaluating the effectiveness of India's legal system, it appears to be well designed. Vohra observed that the judiciary is independent of the other branches of government, and the judiciary is officially a non-political branch of government [2012, 202]. As for the institution that does the biding of the judiciary, the British instituted the ICS in such a way for it to be an effective force for keeping peace and order. The substance of the legal protections for defendants was created in the shadow of the treatment of Indians under British rule; Malik et al. found that Indian Independence Era leaders highly valued civil liberties, having been denied some of them by the British [2008, 47]. Moreover, from a societal and constitutional prospective, India's Constitution has helped to minimize social tensions by allowing for federalism and a multicultural society, as Jyotirindra Dasgupta held [2001, 77]. In terms of the structure of the judicial system and the enforcement of judicial rulings by the bureaucracy, India's legal system appears to be a fairly well structured institution.

Finally, in the evaluation of the legitimacy of the Indian legal system, the evidence supports the claim that there is a respected and working legal system in India. Alfred Stepan et al. maintained that the judiciary (and the Indian government more broadly) is both considered legitimate by the people and exercises control over the people, and this legitimacy is in part due to the sense of national unity that Independence Era created [2011, 47–8]. As with the ICS, the British reformed and standardized the Indian legal

system, but the creation of bodies of law governing religious groups, according to that religious groups' tenets, in certain matters is also a source of legitimacy and tolerance, as Thomas Hansen wrote [1999, 33–4]. Finally, as is consistent with the trend of elites directing and serving in government, elites tend to have a more favorable view of India's state institutions than does the average population [Mitra, 2001, 119–20]. The ethnically sensitive legal codes, the legacy of national unity from the Independence Era, and the backing of the Indian elites also helped to legitimate the Indian legal system.

10 Conclusions About Lipset's Theory in India

In conclusion about democratization in India, Jorgen Pedersen noted that "India is either seen as being too poor, too illiterate, socially and culturally too traditional and ethnically too fragmented to be a likely candidate for a stable parliamentary democracy" [2011, 19]. The problem scholars may have with forecasting democratization in India may be due to what Leela Fernandes noted: India has an institutionally robust democracy but an illiberal culture [2006, 204]. British colonizers established the social conditions for the national infrastructure of education, a bureaucracy, a common language, and a democratic set of values—mainly within the elite class, but they also created the foil, British occupation of India, for India's elites and later masses to rally behind first for independence and then democracy. Indian elites held the economic status, social power, and governing experience to first successfully force the British to withdraw from India, and then Indian elites also helped consolidate India's democracy. Indian elites sought to consolidate democracy in their country because it was in their best interests, according to John Higley and Michael Burton, to institutionalize and minimize the negative consequences of elite conflicts through a democratic form of government [1998, 99]. With wide scale social problems of poverty, illiteracy, and discrimination persisting today, Indian democracy has in some ways been more of a procedural than a substantive success, and the partial success of Indian democracy is, in part, due to the illiberal causes, the socialization by a colonizer and the self-interest of Indian elites, of the Indian democratization process.

11 Conclusions About Lipset's Theory in General

In terms of evaluating Lipset's theory as it applies to India, Alfred Stepan et al. observed that the theory is, "probabilistic, but from the perspective of Lipset's overall framework, India is one of the most over performing democracies in the world" [2011, 42]. In terms of economic and social factors Lipset's theory would not project a transition to democracy and the consolidation of democracy in India. Lipset's theory, however, does anticipate democratization on institutional grounds. In "Some Social Requisites of Democracy", Lipset wrote about indigenous political legitimization of democratic institutions, but he ignored the possibility of an external democratizing force. British colonizers acted as a pre-transition legitimizer of democracy and democratic institutions. Without looking at the role specific classes in society play in the democratization process, Lipset's theory does not account for the disproportionate role elites can play in the democratization process. Lipset focuses on political sociology of countries at-large, but the political history of specific classes (especially elites) is helpful when conducting country-specific studies. Of course, Lipset's aim was to create a global rather than a country-specific explanation of why some countries democratize, so inherently Lipset's theory focused on general conditions rather than specific political actors in the democratization process. In the end, Lipset freely acknowledged the vagaries of whether, why, and how successfully a country democratizes. Lipset wrote, "a particular political form may persist under conditions normally adverse to the emergence of that form. Or, a political form may develop because of a syndrome of fairly unique historical factors, even though major social characteristics favor another form" [1959, 72]. Lipset never claimed to propose a deterministic theory of democratization. Moreover, India falls under Lipset's stated proviso of democracies with "unique historical factors".

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Synaptogyrin

A Novel Longevity Gene

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The following work represents the work done by Richard Escobar for his Engaged Learning project. The synaptic vesicle protein synaptogyrin is up-regulated in p53 long–lived animals, suggesting that synaptogyrin may play a role in the modulation of animal longevity. This project is aimed at characterizing this role.

1 Introduction

The nervous system has frequently been cited as one of the most vulnerable organs during the aging process, as lost cells are not easily replaced. Therefore, protecting neurons may be a major intervention with the potential to yield longevity benefits. Accordingly, inhibiting the pro-cell–death protein p53 specifically in neurons has been shown to increase longevity in a variety of species. In addition, recent studies have shown that synaptic function is a target pathway for p53 [1]. However, it is unclear whether the longevity is due to altered synaptic function. Therefore, this project was aimed at characterizing the synaptic vesicles' role in animal longevity.

Specifically, the synapse is the connection between two neurons in the brain. In an effort to test whether the synaptic vesicle plays a role in animal longevity, we have focused on the synaptic vesicle protein synaptogyrin. Synaptogyrin is a membrane protein located in synaptic vesicles that acts as a scaffolding protein for other important components and thus plays an important role in synaptic vesicle assembly and function [4]. We have recently shown that the synaptic protein, synaptogyrin, is up-regulated in p53 long–lived flies, suggesting that synaptogyrin may play a role in the longevity phenotype [2]. However, we did not know whether the increase in synaptogyrin caused the longevity.

For this reason, we set out to determine whether up-regulation of synaptogyrin is sufficient to increase longevity using the fruit fly *Drosophila melanogaster* as a model organism. We did this by comparing *Drosophila* with increased levels of synaptogyrin versus *Drosophila* with normal levels of synaptogyrin. Additionally, to test whether the longevity effects were due to a neuronal phenotype or a gross phenotype, we tested whether over–expression of synaptogyrin (gyr) affects other phenotypes associated with longevity or neuronal function, such as stress resistance or proper motor control.

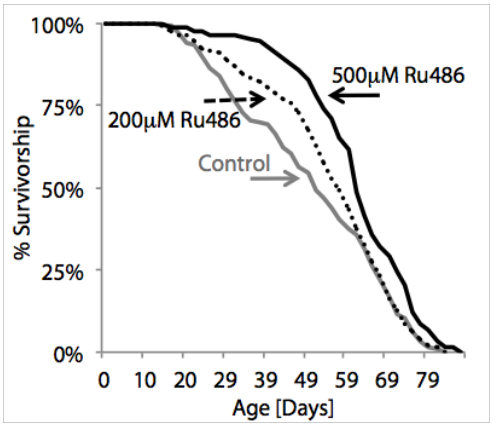

Figure 1: Survivorship curves of synaptogyrin (Gyr 4-1) demonstrate a dose-dependent lifespan extension. A 200 µM RU486 dosage leads to lifespan extension up to 26% in Gyr 4-1 flies, whereas the 500 µM RU486 dosage leads to lifespan extension up to 41%.

2 Experiment

We first set out to determine whether synaptogyrin played a role in longevity regulation of flies. In order to test this, we obtained and constructed multiple *Drosophila* lines with different levels of the protein synaptogyrin through a genetic trick. We observed a

*Mentors: Dr. Johannes Bauer & Stefan Rinaldi, Dedman College, SMU

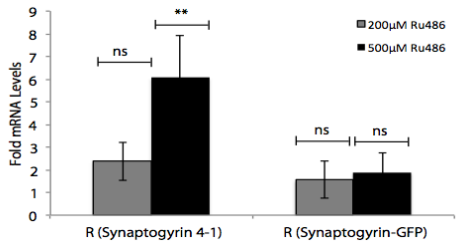

Figure 2: Quantitative PCR (qPCR) revealed Gyr 4-1 mRNA expression is upregulated 2–fold (200 µM) and 6–fold (500 µM), whereas Gyr-GFP mRNA is upregulated only 1.3–fold (200 µM) and 1.9–fold (500 µM).

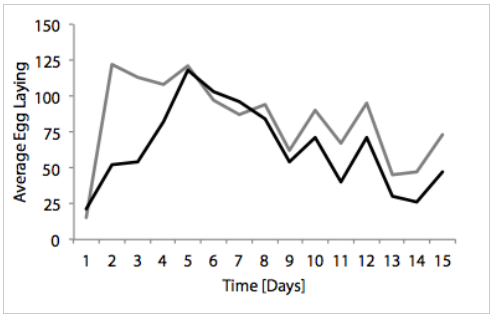

Figure 3: Gyr 4-1 long–lived flies (black) exhibit increased oxidative stress resistance (18%, median LS).

significant increase in lifespan from the flies that had an increased level of the synaptogyrin protein to the control line of flies, which is shown in Figure 1. In addition, this increase in lifespan appeared to be dose–dependent: a greater synaptogyrin dose correlated to an increased lifespan. We confirmed our hypothesis that synaptogyrin's longevity effects were dose–dependent by measuring the synaptogyrin mRNA levels in the different fly lines using quantitative PCR. We observed increased synaptogyrin mRNA levels in the flies that had the longest lifespan, indicating that an increased longevity effect is in fact correlated with increased synaptogyrin levels, as shown in Figure 2.

We next set out to test whether this longevity mechanism had any phenotypic effects on the fly lines. In order to do this, we performed a variety of tests exposing both lines of flies to heat, oxidative stress, starvation, and trauma in order to determine whether there were any phenotypic changes in the long-lived animals compared to controls. Figure 3 shows that the flies with increased levels of synaptogyrin portrayed an increased tolerance when exposed to limited amounts of oxygen. However, the synaptogyrin–mediated flies showed no phenotypic changes compared to the control line when exposed to starvation,

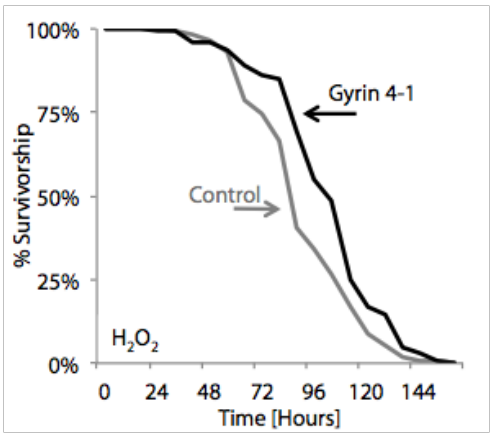

Figure 4: Measurements of locomotor activity, displayed as total activity counts over a 48 hour time period, produced no changes between Gyr 4-1 long lived flies (black) and controls (gray).

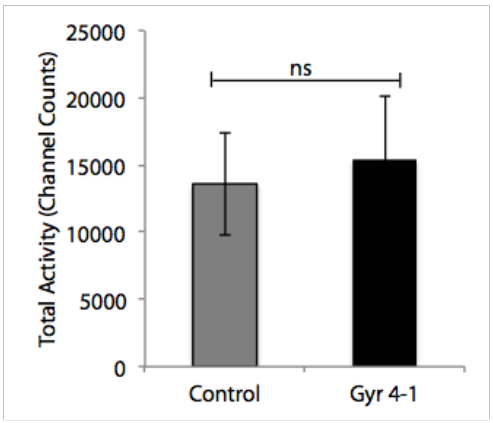

Figure 5: There were no changes in Gyr 4-1 (black) fertility as their total egg counts over a 15 day time period were not significantly different from controls (gray).

heat shock, and trauma.

Following these results, we decided to test whether fertility or locomotion showed any phenotypic changes in the synaptogyrin–mediated flies versus the control. Recent studies have shown a correlation between reduced fertility or locomotion and and increase in longevity in animals [3]. In order to do this, we observed the total number of eggs each line laid each day for 15 days. In addition, we tested both lines' climbing ability and overall locomotion for a period of 10 days. As shown in Figure 4, Figure 5, and Figure 6, there was no noticeable difference in either fertility or locomotion between the synaptogyrin mediated flies and the control.

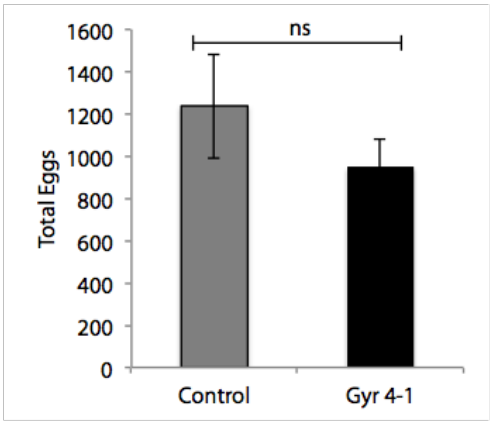

Figure 6: Average egg laying per day appeared to be reduced in Gyr 4-1 long lived flies, but this reduction was not significant enough to produce significant differences total eggs production.

3 Discussion

We initially set out to characterize the role synaptogyrin may play in the modulation of animals. We found there to be a significant life span extension in synaptogyrin flies. However, through our research we discovered that while synaptogyrin–mediated flies are resistant to oxidative stress, this is something commonly found in long–lived animals. We also found that they do not show any other stress–resistant phenotypes, providing us with no other potential phenotypes to consider. Because there were no differences found in fertility or locomotive activity of the synaptogyrin flies, the neuroprotective role of synaptogyrin is all that can be considered. I hope that this research will eventually aid in finding cures for neurodegenerative diseases such as Alzheimer's and will help the neuroscience community get one step closer to making people live longer, healthier lives.

4 Acknowledgments

This work could not have been accomplished without the tremendous support of my advisor, Dr. Johannes Bauer, mentor Stefan Rinaldi, and Engaged Learning. I would also like to thank fellow members of the Bauer lab over the years that were invaluable to me finishing my project: Nithya Joseph, Mehdi Hami, and Sasha Mohammad.

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Birds of a Feather Get Health Care Together

How Marketing and Peer Influence Affect Students' Health Care Decisions

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1 Introduction

In developing this project, I began thinking about how students, especially those not from the Dallas–Fort Worth area, choose certain health care providers when they arrive at SMU with limited knowledge of the different providers available and the particular services they offer. This question arose based on my peers' and my own previous experiences with different providers as well as exposure to marketing research in my Introduction to Marketing course in the fall semester of 2014. As a pre–medical student, thinking about how consumers make choices when presented with different options made me consider possible applications in the health care industry. For example, why does an SMU student from California (who is unlikely to have had previous exposure to Dallas health care providers) go to the QuestCare in Snider Plaza when she could have gone to the SMU Health Center for the same service? Is this student's choice motivated by marketing efforts by QuestCare, peer influence, or some combination of the two?

Ultimately, I wanted to figure out how health care providers near campus market to SMU college students (if at all) and determine how these providers' marketing efforts as well as peer influence affect students' perceptions of these providers and their services. My hypothesis was that health care providers around SMU do little to directly market to students; however, input and recommendations from upperclassmen students have a strong influence on other students' health care choices.

2 Project Design

With guidance from my mentor, Dr. Morgan Ward, I determined that a fairly comprehensive survey of a large sample of students would be the best way for me to observe any possible in students' health care decision making and what or who influenced them. This survey included questions such as what provider qualities were most important to them; which providers in the SMU area respondents had used; whether or not they received advice from upperclassmen, and how accurate they believed that input to be; what kinds of marketing from providers they had seen; and a wide range of demographic questions.

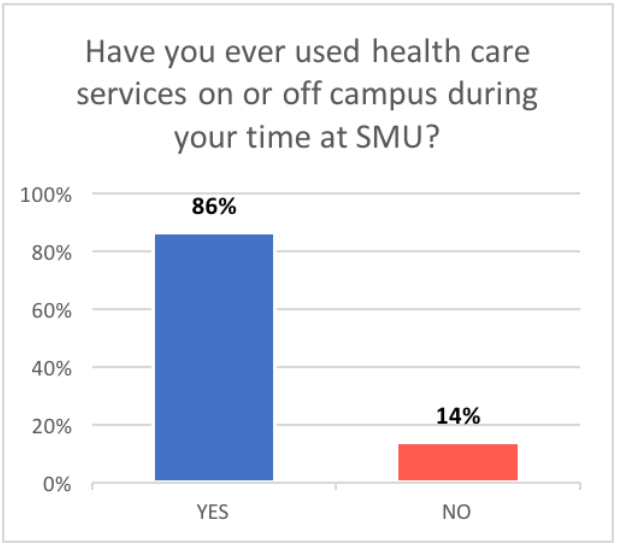

Figure 1: Percentage of students surveyed that have used or not used health care services while at SMU.

The survey was approved by SMU's Institutional Review Board and was distributed both online and through the SMU Marketing Subject Pool to SMU undergraduate students exclusively. During the summer and fall of 2015, more than 180 students started and completed the survey, giving a solid sample size of students to start to observe decision making trends. The survey was developed, conducted, and analyzed using Qualtrics Survey Software.

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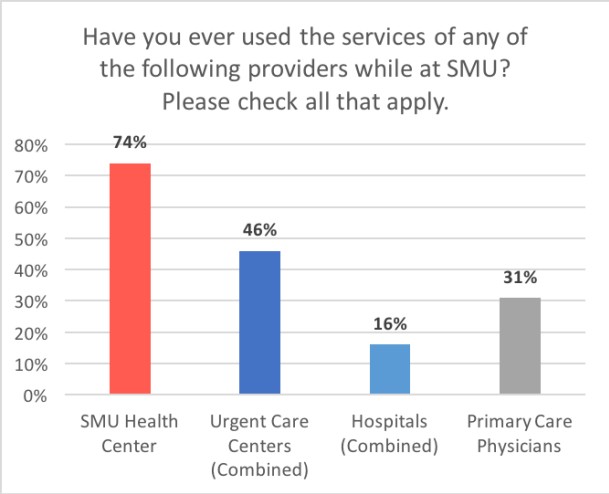

Figure 2: Percentage of respondents that have used the services of different types of health care providers near campus while at SMU.

3 Background

Health care is a complex industry to navigate as a consumer. In this section, some of the reasons for this complexity will be addressed, particularly as they relate to SMU students' health care decision making. These elements include the concept of credence goods, the wide variety of health care providers available to SMU students, and the impact of peer influence on a person's decision making process.

3.1 Medicine as a Credence Good

Health care, similar to a handful of services such as auto repair and computer servicing, is what is called a "credence good", meaning that the expert who is performing the service knows more about the quality that consumers need than the consumers themselves [Dulleck and Kerschbamer, 2006]. While we as consumers are fortunate to have such experts to rely on when these services are needed, the very complexity of the service itself means that we likely face a number of informational problems in ensuring the quality of the service we receive.

One obvious risk from this discrepancy of expertise is the potential for the consumer to be defrauded, either for services that they did not receive, or services that they received but did not actually need [Dulleck and Kerschbamer, 2006]. While this problem is certainly present in the health care market today, the issue with credence goods that underlies the core of this project is the definition of the theory itself: consumers (in this case, college students) lack the knowledge to fully understand the service they are receiving and to be able to properly evaluate options.

the scope of this project, college students have a difficult time differentiating between providers and their services because they, understandably, do not have the requisite knowledge to decipher such a complex and variable system. This information problem leads students to rely on "shortcuts" to help them make health care decisions, such as seeking out advice from peers or looking to information and marketing from the providers themselves. This study looks at these two shortcuts specifically to try to determine which of the two plays a more significant role in the decision making process of the typical SMU student.

3.2 Diversity of Providers

As if determining the quality of a health care provider was not difficult enough, the sheer quantity of providers in the Dallas area, and particularly in a 10– to 15–mile radius of SMU's campus, is enormous. For the sake of this study, I chose to focus on four distinct types of health care providers: the SMU Health Center, urgent care centers, major hospitals, and primary care physicians.

The SMU Health Center provides on–campus health services with full–time nurses and physicians on staff. It offers a very geographically–close option for students, more than 60% of whom live on campus, although its hours of service are not as extensive as other options such as urgent care centers and hospitals.

Urgent care centers such as QuestCare, PrimaCare, Concentra, and CityDoc, just to name a few, have been increasingly popping up around Dallas over the past five years or so. While the phenomenon of urgent care centers and their offerings as a business model is fascinating itself, the primary facts relevant to this study is that these centers are within a 2– to 10–minute drive of SMU's main campus and offer extended hours with short wait times.

Most consumers are likely at least indirectly aware of the kind of service model provided by major hospitals. Three major Dallas hospitals are within a 10– to 15–minute drive from SMU: Texas Health Resources Presbyterian Hospital Dallas, Baylor University Medical Center, and UT Southwestern Medical Center (includes Parkland Hospital). These hospitals are open 24 hours a day and provide high–level emergency and specialty care.

Since a notable percentage of SMU students are from the Dallas/Fort Worth area, I also wanted to look at the services provided by primary care physi-

cians (PCPs). As a native Dallasite myself, I go to my PCP for services that other students might go to the Health Center or an urgent care center for. Primary care physicians, while they often have more limited office hours, offer high–quality care, appointment scheduling, and should best understand your medical history.

While these four types of health care providers are not all–encompassing in terms of the types of providers available in the Dallas area, these four represent the most likely choices for SMU students as they seek out health care services during their college years.

3.3 Peer Influence

As studies have proven again and again over the past six decades of marketing research, word–of–mouth referrals are one of the strongest influences on our attitudes and behaviors as consumers. In a 1965 study by Feldman and Spencer, two–thirds of new residents in a community relied on word-of-mouth (WoM) referrals to choose a physician [Brown and Reingen, 1987]. At SMU, just over 50% of students are from outside of Texas, let alone from outside of the Dallas area. This statistic makes a large "new resident" population that is likely to rely on WoM information from peers.

4 Results and Discussion

More than 180 SMU students started and completed the survey, developed for this project using Qualtrics Survey Software, during the summer and fall of 2015. In the section below, the major results of the survey will be discussed. The primary result categories include the demographic and usage statistics, the ranked importance of provider qualities, an assessment of provider's performance on these qualities, peer influence effects, and finally provider marketing exposure.

4.1 Demographics and Health Care Use

Respondents represented every class and 28 states of residence, plus international students, with just over half of respondents being past or current Texas residents (53%). Of the Texan respondents, 68% had previously or currently live in the DFW Metroplex, which includes Collin, Dallas, Delta, Denton, Ellis, Hunt, Johnson, Kaufman, Parker, Rockwall, Tarrant and Wise counties. Over four–fifths of respondents have a car on campus, with 93% living on- campus or less than 5 miles away.

Of those surveyed, 86% have used health care services either on or off campus during their time at SMU (Figure 1). The academic class designation of the respondents was not asked, but this characteristic likely would have corresponded with health care use, with first–year students in their first semester being less likely to have needed health care services.

The breakdown of which providers students have frequented is shown in Figure 2, with the SMU Health Center (74%) and urgent care centers (46%) being the most visited. The services of primary care physicians were used by 31% of respondents, which corresponds with 75% of DFW resident respondents saying that they still use their primary care physician while at SMU.

4.2 Important Provider Qualities

Two key aspects of this survey were determining which qualities of health care providers students considered most important, and how they rated providers on these qualities. In Figure 3, the results of the quality ranking are shown based on the seven qualities assessed: cleanliness, appointment wait time, distance from your residence, cost, quality of care, ease of appointment scheduling, and hours of operation. Participants were asked to rank these qualities from 1–7, with 1 being the most important to them and 7 being the least important to them when selecting a health care provider while at college. This figure shows scores of greater importance in the darkest shades of blue, with the bars getting lighter in shade as more "less important" scores were given.

Based on this question, quality of care was far and away most frequently identified by students as being of the highest importance to them in selecting a provider. Next was hours of operation, followed by ease of appointment scheduling, cost, and distance from your residence. Cleanliness and appointment wait time were the least important qualities to student respondents.

4.3 Positive Provider Qualities

Next, survey participants were asked to determine which of these seven qualities the four types of providers did well. Respondents could select as many "positive" qualities for the four types of providers as they chose to. These results are depicted in Figure 4.

While some providers stand out for being rated particularly well by students in certain qualities, one particularly interesting result was that urgent care centers received fairly good marks across the board,

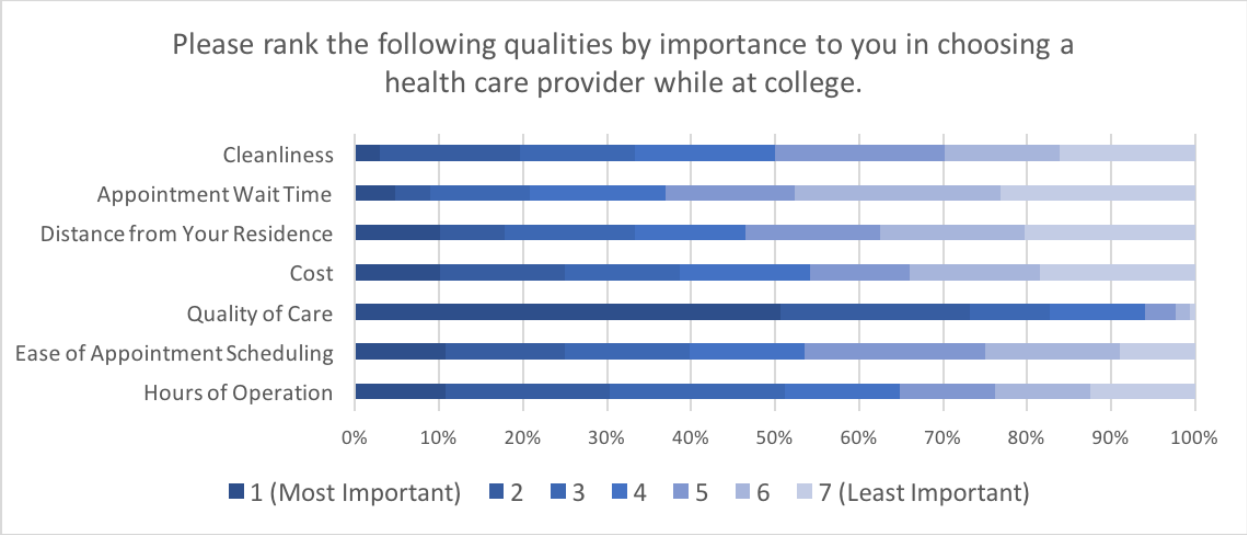

Figure 3: Ranking of importance of seven health care provider qualities, with the darker shades of blue being more important and the lighter shades representing lower importance ratings.

with only one of the seven qualities having less than 50 responses from students.

Indeed, the median number of positive ranks for urgent care centers was 7 more than the next highest, the SMU Health Center (63 vs. 56), while hospitals had a median of 20 positive ranks and primary care physicians had a median of 43.

In Figure 3, quality of care was shown to be the most important health care provider characteristic to students when choosing a provider. As depicted in Figure 4, the SMU Health Center was rated much lower on this characteristic as compared to the other providers, with primary care physicians being most frequently rated positively on this quality by student respondents. While the Health Center seems to have an edge in distance from your residence, cost, and ease of appointment scheduling, students reported that characteristics were less important to them than quality of care and hours of operation.

While urgent care centers only led two of the seven categories in positive ranks by students, it seems that their fairly solid performance across all of the categories, and especially in the top two most important qualities, could be a driver of these centers' popularity with student consumers.

4.4 Peer Influence Effects

Next, the idea of peer influence was indirectly addressed with student participants. Students were asked what different "types" of fellow students that they typically sought out information about health care providers from (shown in Figure 5), as well as if these students had particular expertise for certain reasons, and to what degree they trusted these sources. Overall, students somewhat to significantly trusted 86% of the peers that they go to for information about health care providers, backing up the idea that their word-of-mouth referral information is coming from strong ties.

Similarly, students were asked if they 1) heard about the SMU Health Center and then urgent care centers from upperclassmen students during their first year at SMU, as well as 2) what their first impression of these providers were based on this upperclassman guidance, and 3) if the respondent felt that these opinions were accurate when he or she experienced the provider themselves.

Based on the responses to these questions, 65% of student respondents heard about the SMU Health Center from upperclassmen; of those of who did, a combined 67% of those opinions indicated that the Health Center was neutral, unreliable, or very unreliable. To put this in context, almost half of the 180+ students that took this survey had an upperclassmen peer indicate to them that this provider was, at best, not even in the "reliable" category. This result is a significant indication that students look to and remember the opinions of other students, whether well–founded or not, when they are choosing a health care provider.

Alternatively, only 41% of respondents heard about urgent care centers from upperclassmen, but of those who did, a combined 65% of the opinions viewed these centers as either reliable or very reliable. Clearly (and again, whether for well–founded reasons or not),

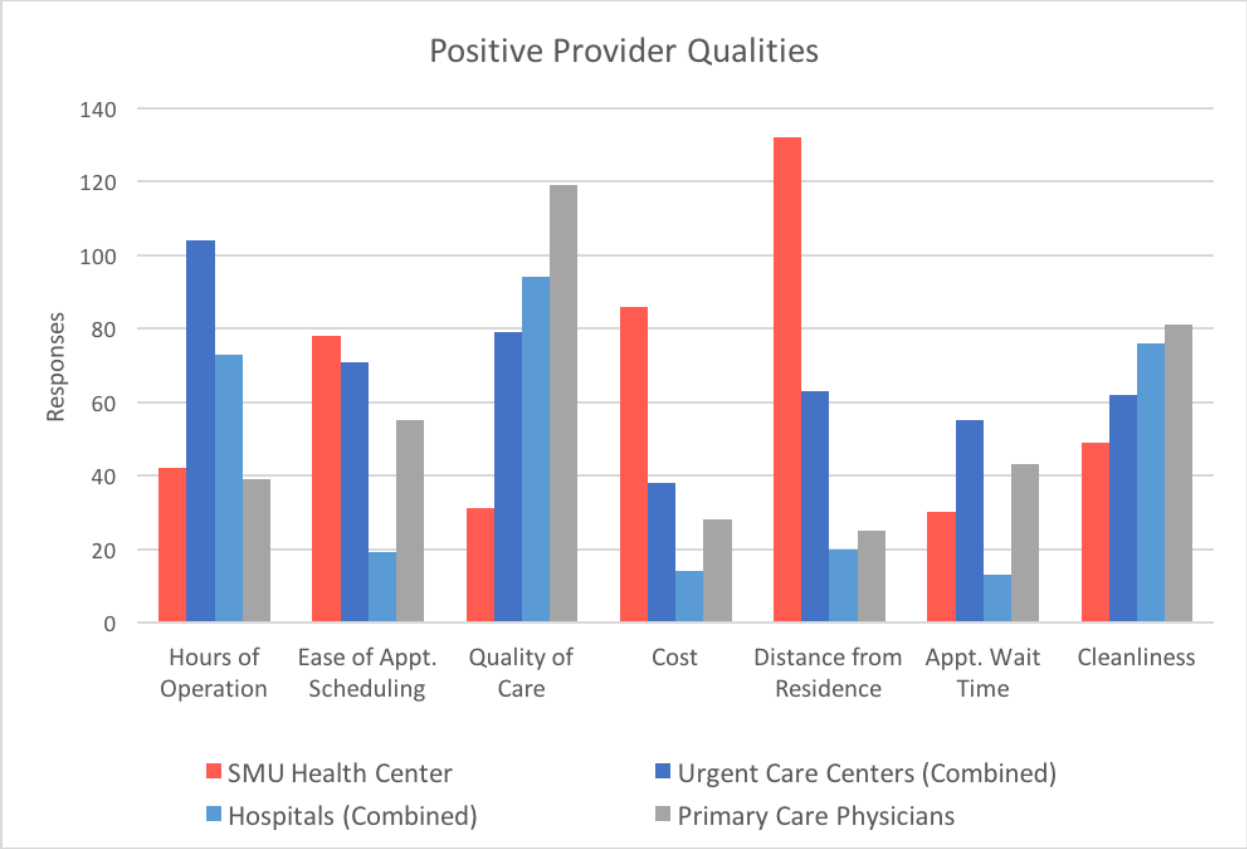

Figure 4: Assessment by respondents of how well each provider type performs on the seven health care provider qualities previously ranked in Figure 3.

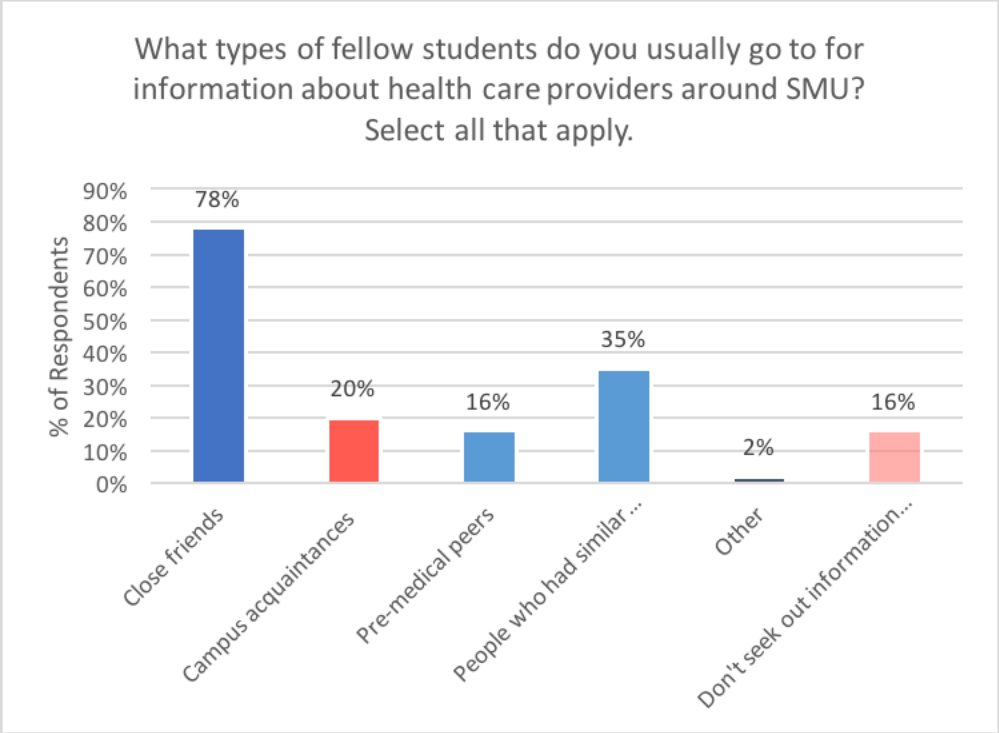

Figure 5: Percentages of respondents who seek out health care provider information from each type of peer.

the peers that these students heard from had specific opinions about their health care provider preferences that they were willing to share with other students.

Interestingly, when results of these questions were cross-tabulated with gender, very similar trends were seen among both male and female participants.

4.5 Provider Marketing Exposure

Finally, students' exposure to provider marketing and information was assessed by asking if they had ever sought out information online about a particular provider or had ever received direct marketing materials such as a postcard, magnet, or flier from a health care provider.

As depicted in Figure 6, an overwhelming 96% of survey respondents reported having sought out information online about health care providers. For a generation that is so accustomed to searching out information online for almost every aspect of their academic and personal lives, this result certainly makes sense, especially considering the information inequity inherent in health care as a credence good. Since students are often new to the Dallas area, the internet is an easy, very accessible first tool for them to use to gain more information about a particular provider before they look for other sources (e.g. their peers).

Only 21% reported receiving marketing materials

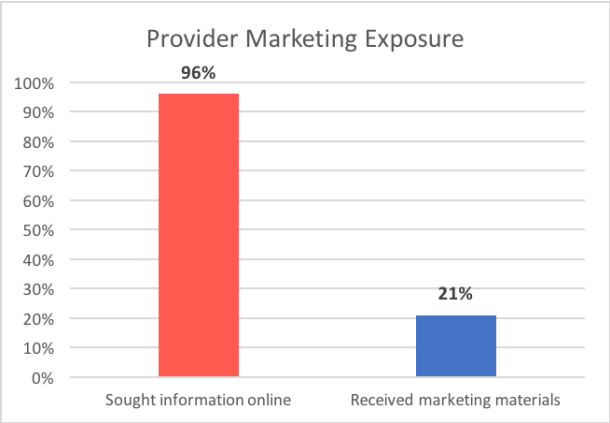

Figure 6: Percentage of students surveyed who had been exposed to marketing from any health care provider, both online and physical materials.

from the providers themselves, but the actual number is likely higher since it can be difficult to remember receiving these kinds of marketing materials that many people immediately recycle or discard. Regardless, students were much more likely to seek out information on their own terms than to receive information directly from the provider.

In either case, the health care providers have ultimate control over what content and what format this

information is offered in. While urgent care centers often showcase their short appointment times and long hours of operation, hospitals market their quality of care. Primary care physicians promote their credentials and patient information, while the SMU Health Center homepage offers many different links based on its variety of functions for the student body. With many consumers, not just college students, using these sites as at least a first stop for information about their services, these providers need to be thoughtful about how they present their information and market to their consumers.

5 Conclusions

Based on the results of this project, it seems most likely that most SMU students use provider-controlled information and marketing channels as an initial, more surface–level source of information, but really base their decision making process on the input of friends, specific acquaintances, or other trusted sources. This conclusion is particularly applicable to those students coming from outside of Dallas and outside of Texas, as they have virtually no previous exposure to Dallas health care providers and their quality and offerings of services.

While further qualitative study could be done about the basis of these opinions that are passed through word–of–mouth referrals, the blunt reality is that regardless of how much fact these opinions are based on, they are being shared. For providers looking to improve their reputation in the eyes of students, students themselves should be the target of their appeals as potential opinion leaders on campus. In this case, while provider–controlled information may be referenced, peer influence seems to have the much stronger upper hand in its power to influence.

This result aligns well with previous literature on the subject, suggesting that this sample of students would be representative of other types of consumers. While specific demographic and situational factors are also in play, these seem to, if anything, ameliorate the effects of peer and social influence on this group with so many students being new to the area and in such close quarters with each other.

So why does a new student from California choose to go to QuestCare instead of the SMU Health Center for a condition that could be treated by both providers? Likely because her roommate who also suffered from pink eye three weeks ago also went to QuestCare, and the roommate went because a sophomore in her Spanish class recommended it over the other options. And last year the sophomore heard from a senior teammate on the Mock Trial team that QuestCare was better, and on and on it goes....

6 Acknowledgments

I am extremely grateful for the support of Dr. Morgan K. Ward, my Engaged Learning Mentor, in developing and carrying out this project. I would also like to express a sincere thank you to all of the students who participated in this study, and finally to the SMU Engaged Learning Office for approving and funding this project.

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Developing Hollow Optical WGM Resonators as E–Field Sensors for Use in Advanced Prosthetics

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Abstract

The overarching purpose of this research is to develop brain/body–machine interface devices for the improved control and use of advanced (robotic) prosthetic devices. Specifically, we aim to create implantable, biocompatible, WGM–based electric field sensors that are small enough, sensitive enough, and capable of detecting signals fast enough to intercept nerve impulses as they happen in real time. Though previously created sensors have been able to detect $1.8\,\mathrm{V/m}$ electric fields, we were only able to detect this field strength at electric field modulation frequencies of $0.2\,\mathrm{Hz}$ [4]. In order to sense a neuron firing, we need to detect, with similar or greater sensitivity, signals with modulation frequencies of greater than $1\,\mathrm{kHz}$, since the typical duration of the electric field spike associated with a neuron firing is on the order of one millisecond. While we were unable to reach our end–goal of manufacturing and testing electric field sensors capable of detecting external inputs at greater frequencies, we have made significant progress toward this goal by attempting the two most promising manufacturing methods for producing hollow optical WGM micro–resonators, which should theoretically outperform the non–hollow WGM sensors we use now.

1 Introduction

At its most basic level, our sensors take advantage of the Whispering Gallery Mode (WGM) Phenomenon, also called Morphology Dependent Resonance (MDR). Lord Rayleigh first mathematically described the Whispering Gallery Mode Phenomenon in 1910, giving him the ability to explain why one is able to hear a whisper in a very large domed room, provided that the source of the sound and the receiver of the sound are both in close proximity to the edge of the dome [12]. Lord Rayleigh confirmed, through his experimentation in St. Paul's Cathedral, that rather than decaying as the inverse of distance squared, the intensity of sound constrained by a dome decays as the inverse of distance, allowing much greater propagation of acoustic waves than in free space [11].

Luckily, WGM resonances are also possible in optical cavities using light rather than acoustic waves. In fact, WGM effects appear stronger in light, with quality factors (essentially the ratio of stored energy to energy being lost or dissipated) in excess of 10^{10} having been measured for optical resonators, whereas comparable acoustic resonators can maximally attain a quality factor on the order of 10^4 [6].

We take advantage of this phenomenon by using a tunable DFB laser to provide a source of light in the $1.3\,\mu\mathrm{m}$ wavelength range, which can be tuned with picometer precision. This light is then injected via thinned optical fiber (silica coated with plastic cladding) into our optical resonator, a microscale sphere (generally in the 80–$800\,\mu\mathrm{m}$ diameter range), through quantum tunneling. The light then travels the circumference of the sphere, an optical path length of

$$2\pi n_0 a$$

where a is the radius of the sphere and n_0 is the refractive index of the sphere. Assuming that the optical path length is an integer multiple of the wavelength, the light then tunnels out of the sphere and interferes with the light passing through the optical fiber, resulting in a change in the light received by the photodiode [9]. A simplified version of this experimental setup can be seen in Figure 1. By scanning the DFB laser over a range of wavelengths (and using the optical resonance condition of the sphere:

$$2\pi n_0 a = l\lambda$$

*Mentor: Dr. M. Volkan Ötügen, Professor and Chair of Mechanical Engineering, Lyle School of Engineering, SMU

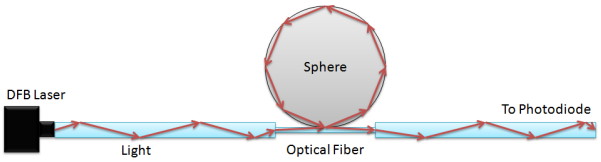

Figure 1: Optical WGM Resonance Setup

where l is the mode number and λ the varying wavelength of light, and assuming that $a \gg \lambda$, a required condition for WGM resonance) we are able to detect any change in morphology (sphere radius) or refractive index of the sphere. We can then correlate that change, via the change in wavelength of a particular interference mode, to some outside phenomenon or force in real time [4].

Due to the dielectric property of polydimethylsiloxane (PDMS), the biocompatible optical polymer we selected, out of which our micro–resonators are made, we can detect a change of morphology in the sphere, specifically of the radius of the optical path, when a varying electric field is applied to the sphere [9]. We take advantage of this property in order to make our optical resonators act as sensing elements for electric fields.

2 Prior Work

Before this project began, the researchers of the Micro–Sensor Lab were able to increase the electric field sensitivity of micro–sphere sensing elements from hundreds of volts per meter to our highest sensitivity of $1.8\,\mathrm{V/m}$ [4]. What drives the continuation of this research is that, though our sensors are able to detect $1.8\,\mathrm{V/m}$ varying electric fields, we were only able to detect this field strength at electric field modulation frequencies of $0.2\,\mathrm{Hz}$ (Ali, 2015). In order to sense a neuron firing successfully, we need to be able to detect, with similar or greater sensitivity, signals that are much faster than $0.2\,\mathrm{Hz}$. Since the typical duration of the electric field spike associated with a neuron firing is on the order of one millisecond, we know that we need to be able to measure electric fields with modulation frequencies of greater than $1\,\mathrm{kHz}$.

3 Vibration Theory

In order to determine how to proceed, we decided to conduct a vibration–based analysis of WGM sensors. Our sensors can be modeled (to first order approximation) as an over–damped simple harmonic oscillator, with visco–elastic effects causing the sensor to return to its original shape when external forces are removed (assuming elastic deformation) and a loss of energy, equivalent to damping in an oscillating system, caused by the viscous nature of the polymer. Given this approximation, we know that we must maximize the amplitude of oscillation (equivalent in this case to the optical path length) in order to increase the sensitivity of the sensor. Simultaneously, we must increase the frequency at which the sensor can be forced via application of an external electric field.

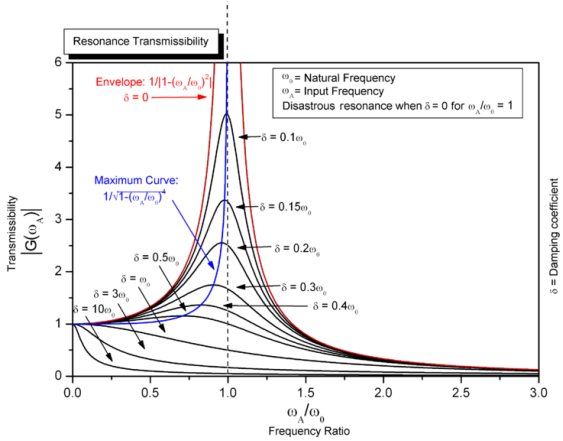

Figure 2: Transmissibility/Frequency Ratio Plot

From basic vibration theory, we know that in order to maximize the vibrational response of an oscillator, there are two parameters that one can adjust. These are the damping coefficient and the frequency ratio (between the input—in this case the electric field modulation frequency—and the output— the sensor's natural frequency). As can be seen in Figure 2, the maximal transmissibility—in other words, the maximal response amplitude for a given forcing amplitude—occurs in the limit as $\delta \to 0$ and $\frac{\omega_A}{\omega_0} \to 1$ [8]. Since altering the damping coefficient, δ, requires altering the material properties of the optical polymer that the sensors are composed of, and, since ω_A, the input or modulation frequency of the electric field, is fixed by neuro-biology, we know that altering ω_0, the natural frequency of the sensor, is our only hope for increasing its sensitivity. Again, using the simplification of our sensor as a simple harmonic oscillator, we can approximate its natural frequency by using the natural frequency of a simple harmonic (spring-mass) system, namely

$$\omega_0 = \sqrt{\frac{k}{m}}$$

where k is the spring constant and m is the mass (in

this case, the mass of the sensor). Furthermore, since it is difficult to alter the viscoelastic properties of the polymer, which directly influence k, without changing its optical properties, our conclusion was that reducing m will boost the natural frequency of the sensor, leading to increased response amplitudes at higher frequencies.

From this theoretical conclusion, we hypothesize that making the spheres hollow would decrease the mass significantly enough to see an increase in amplitude response (sensitivity) at higher frequencies. This hypothesis is the driving factor behind the research of this project. Regrettably, we are, as of yet, unable to produce hollow spheres which are capable of supporting WGM resonances. However, in order to manufacture hollow micro-spheres we attempted two different manufacturing methodologies, described below, which show promise with some additional research.

4 Coated Commercial Hollow Sphere

One of the major problems with creating hollow micro-scale optical spheres is, as the reader can probably guess, the fact that it is extremely difficult to produce an 80–$800\,\mu\mathrm{m}$ diameter hollow microsphere, in a lab setting. Challenges in manipulating uncured spheres, curing the spheres while retaining a perfect (or close to perfect) spherical shape, and assuring that the air phase portion of the sphere is concentric with the PDMS shell, are chief among the manufacturing difficulties. There are, however, commercially available hollow polymer microspheres, which are used as fillers and additives in a very broad range of products, from paints and glues to concrete. The manufacturers of these spheres have managed to solve these production problems through the use of multi-million dollar manufacturing equipment and processes, which are unfeasible to acquire for lab use—at least until the efficacy of these sensors has been established in an advanced prosthetics application.

These expanded microspheres, as the industry has dubbed them, are unfortunately not made of an optically compatible polymer, as we were able to determine in the initial stages of the project. Therefore, they cannot be used on their own as WGM resonators. Fortunately, these expanded microspheres have extremely low densities, in the 15–$55\,\mathrm{kg/m^3}$ range, according to their manufacturers. (For reference, air has a density of $1.2\,\mathrm{kg/m^3}$ at STP [2], only one twelfth that of our lightest microspheres). Furthermore, the microspheres exhibit wall thicknesses: the thickness of the polymer shell is in the sub–$2\,\mu\mathrm{m}$ range for spheres that have a mean diameter in the 55–$165\,\mu\mathrm{m}$ range [7, 3]. These properties make commercially available hollow microspheres excellent candidates for creating PDMS coated microspheres that we hypothesize should be able to support optical resonance and exhibit reduced damping.

The major focus of our research in this stage of the project was to develop a method for coating three different types of commercially available expanded (hollow) microspheres, which are in their original form unusable, with a thin layer of PDMS polymer. Additional goals consisted of determining safe handling procedures for the expanded microspheres[1], determining how to control the thickness of the coating (as it should be intuitive that the thicker the coating the more damping the sensor will experience), determining how to control the morphology of the resultant coating (as it is remarkably difficult to achieve an even coating due to gravitational and surface tension effects), and, finally, to determine whether these coated hollow microspheres can support WGM resonance, exhibit improved sensitivity, and detect faster signals.

While we were not able to meet all of our goals during this stage, we did make significant progress: we were able build a dead–air (minimal airflow) glove box, pictured in Figure 3, and to develop a safe handling procedure, which uses theoretical models for particle settling time based on particle size and density and a capture mechanism for settling microspheres, to assure safe handling. While this might not sound like much of an accomplishment, this advance was crucial to being able to conduct our research, as the microspheres are so light that they are impossible to manipulate in a standard fume hood (the air currents are far too strong and tended to aerosolize the fine powder) and too potentially hazardous to manipulate in open air. Furthermore, we were able to determine a procedure to successfully coat the hollow microspheres and control not only the coating thickness, but also, to a large extent, the morphology of the coating.

One of the coated hollow microspheres, made using a procedure we developed during this stage, is depicted in Figure 4. The major problem with these spheres is that we were unable to measure stable WGM resonance, and have therefore been unable to determine the sensitivity and minimum signal duration of these WGM resonators. We hypothesize that this is due to the uneven morphology of the coating, which causes catastrophic scattering losses when-

[1] While they are not toxic, their small size and low density makes them an inhalation hazard and a danger to sensitive optical equipment.

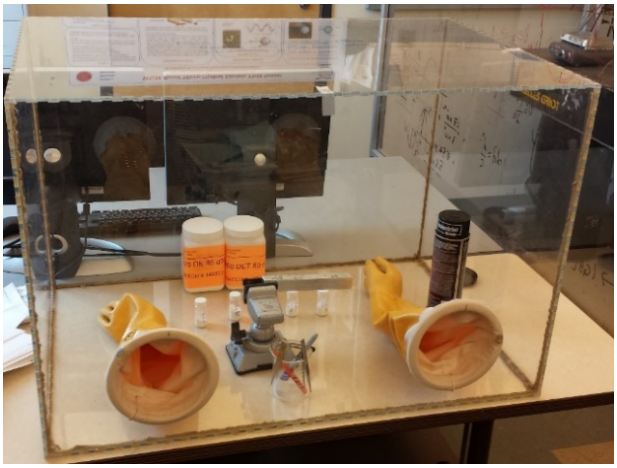

Figure 3: Micro-Sensor Lab Dead–Air Glove Box with Various Tools and Commercial Hollow Microsphere Samples

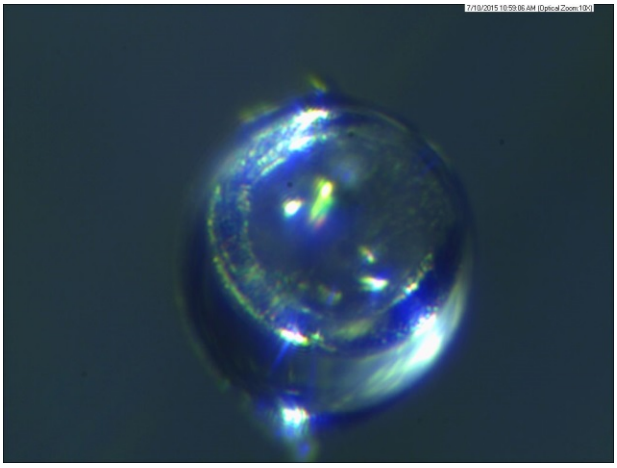

Figure 4: Akzo Nobel Expancell 920 DE 80 d30 Coated with 20:1 PDMS using the Hot Polymer Base procedure. Mean coating thickness is $21\,\mu m$, hollow sphere diameter is $145\,\mu m$. The large inner sphere is the uncoated AN Expancell Microsphere, which is coated with PDMS polymer and manipulated using an optical fiber stem, visible at the bottom of the figure.

ever the coating thickness becomes too thin. Figure 5 shows three further examples of coated commercial hollow spheres, each with the same fatal flaw: The coatings are excellent on one side and too thin, or nonexistent, on the other. Also of concern was the fact that stem penetration of these spheres was complete: the optical fiber stem we use to manipulate the spheres penetrates the entirety of the coating, which is also known to contribute significantly to scattering losses.

Given all of these problems, we decided to shift gears and attempt to sidestep these problems by attempting to manufacture stemless hollow microspheres in house, rather than continuing to try to coat commercial hollow spheres.

5 Micro-Fluidic Hollow Sphere

We decided to continue our research by attempting a micro–fluidic manufacturing process, rather than continuing with our previous process. Hollow microspheres, as we describe them, are known in the field of microfluidics as microbubbles or air/oil/water–phase double emulsions, since that describes the various phases of the microsphere, from inside to outside. The oil phase is our polymer, PDMS, and a water phase is introduced as a carrier fluid to help the formation of individual spheres.

These multiple emulsions are relatively common, even to very high order, with multiple alternating layers of oil and water. Abate and Weitz demonstrate that quintuple emulsions of oil and water are possible: sets of concentric spheres or shells of oil/water/oil/water/oil/water have been produced [1]. Single and double emulsions are shown in Figure 6. The complexity in producing these emulsions for our purposes is twofold: Firstly, air/oil/water emulsions are significantly more difficult to create (but not impossible [5]), and, for easy manual manipulation, we require the spheres to be in the 200–$800\,\mu m$ diameter range, with published applications generally on the lower end of this range [5].

There exist two main manufacturing methods available to create these microbubbles (air/oil/water double emulsions): co-flow pipette–based devices and double droplet generators. Given the published success of the double droplet generator and the availability of photolithography equipment in the Lyle School of Engineering, we decided that this approach represented the best chance of success [5]. A single droplet generator and a double droplet generator are shown in Figure 7. These devices work by injecting the inner phase, air (from the center left), and the middle phase,

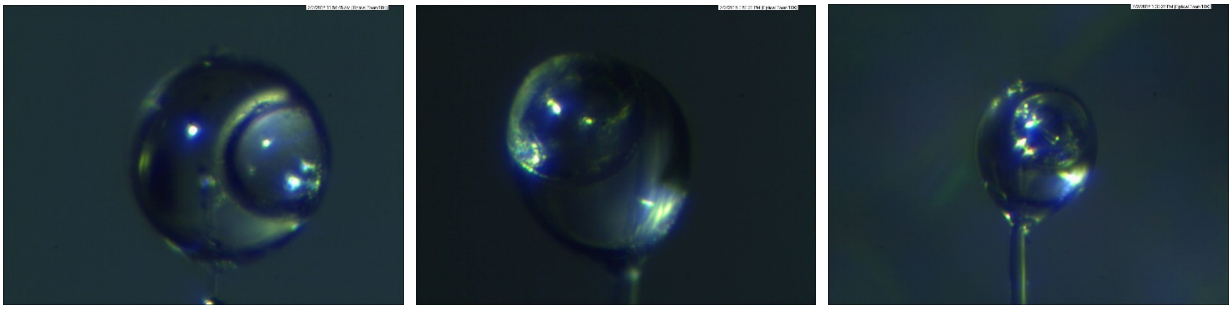

Figure 5: Further attempts to coat commercial hollow spheres with PDMS produce no measurable WGM.

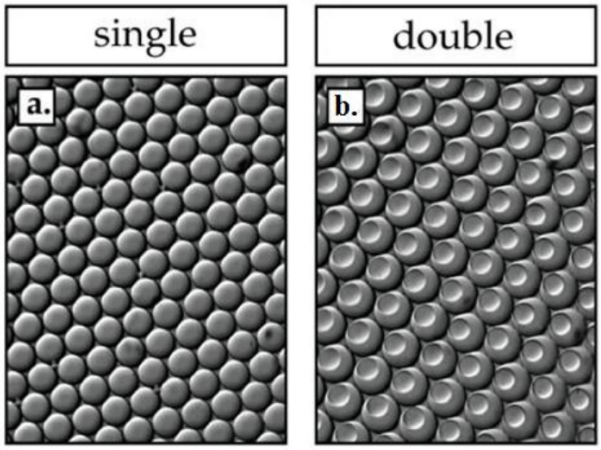

Figure 6: Single emulsion: oil/water. Double emulsion: air/oil/water [1]

PDMS, from the top and bottom (left) simultaneously. This action causes the formation of alternate phases of PDMS and air. A second junction, only shown in the double droplet generator (Figure 7) injects water from the top and bottom (slightly left of center) allowing the water phase to break up the air/PDMS emulsion and generate the double emulsion. The spheres are then photo–cured or heat–cured and extracted from the water.

Manufacturing double droplet generators presents its own problems. Currently, the most efficient process for manufacturing these devices is soft-photolithography. "Soft", in this instance, refers to the fact that the final device is made of soft elastomers, such as PDMS, and is therefore somewhat flexible. This designation is used to distinguish it from other photolithography processes where the substrate is usually silicon. Traditional subtractive manufacturing processes are not generally possible at this scale and additive 3D printing processes with this resolution are often prohibitively expensive, leaving us with photolithography as the only viable manufacturing process.

The photolithography process is described in detail in Figure 8, but in short, the photoresist is applied to a clean substrate, a photomask is applied and exposed to UV light, and, finally, the excess unexposed resist is developed (removed). A mold of the device is then made and the necessary access ports are connected to introduce air or liquid into the correct channels.

Our photomask can be seen in Figure 9, with the colors inverted for easier viewing. When our photomask is used, what we see here in black is transparent, allowing UV light to cure the photoresist underneath it. Everything else is opaque to block the UV light resulting in uncured photoresist. The large circles at the ends of the channels serve as access ports, through which the air, PDMS, and water are introduced, as well as the exit port (the largest and rightmost circle). Air is introduced from the leftmost access point, PDMS from the top and bottom (left of center) access points, and water from the top and bottom (right of center) access points, with the exit being the remaining access point. The channel size at each junction is increased in order to promote sphere formation.

One of the continuing problems of this Engaged Learning Project has been developing (or removing) the uncured photoresist in order to be able to mold the photoresist in polymer. To be able to create spheres of a size, which can be manually, manipulated (our target being at the larger end of the range, approximately $750\,\mu\mathrm{m}$), we need a uniform photoresist thickness of approximately $750\,\mu\mathrm{m}$. This is required in order to maintain the proper aspect ratio in the channels, which is important since this affects how spherical or ovoid our hollow spheres become. Compared to most photolithographic devices, however, this thickness is absurdly high and almost unheard of, but not impossible to attain [10].

In a proof of concept experiment (conducted at the beginning of fall 2016), we were able to create a channel easily, with a photoresist thickness of approximately $100\,\mu\mathrm{m}$, using the photoresist SU- 8 3025, from

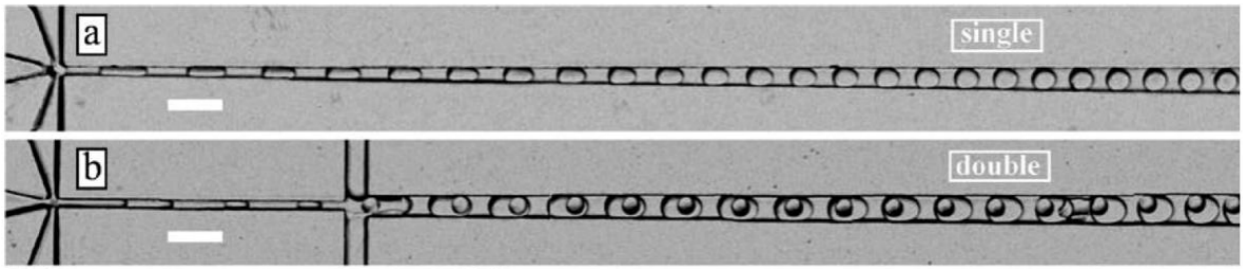

Figure 7: Single–intersection device creating oil/water spheres and double–intersection device creating air/oil/water spheres [1]

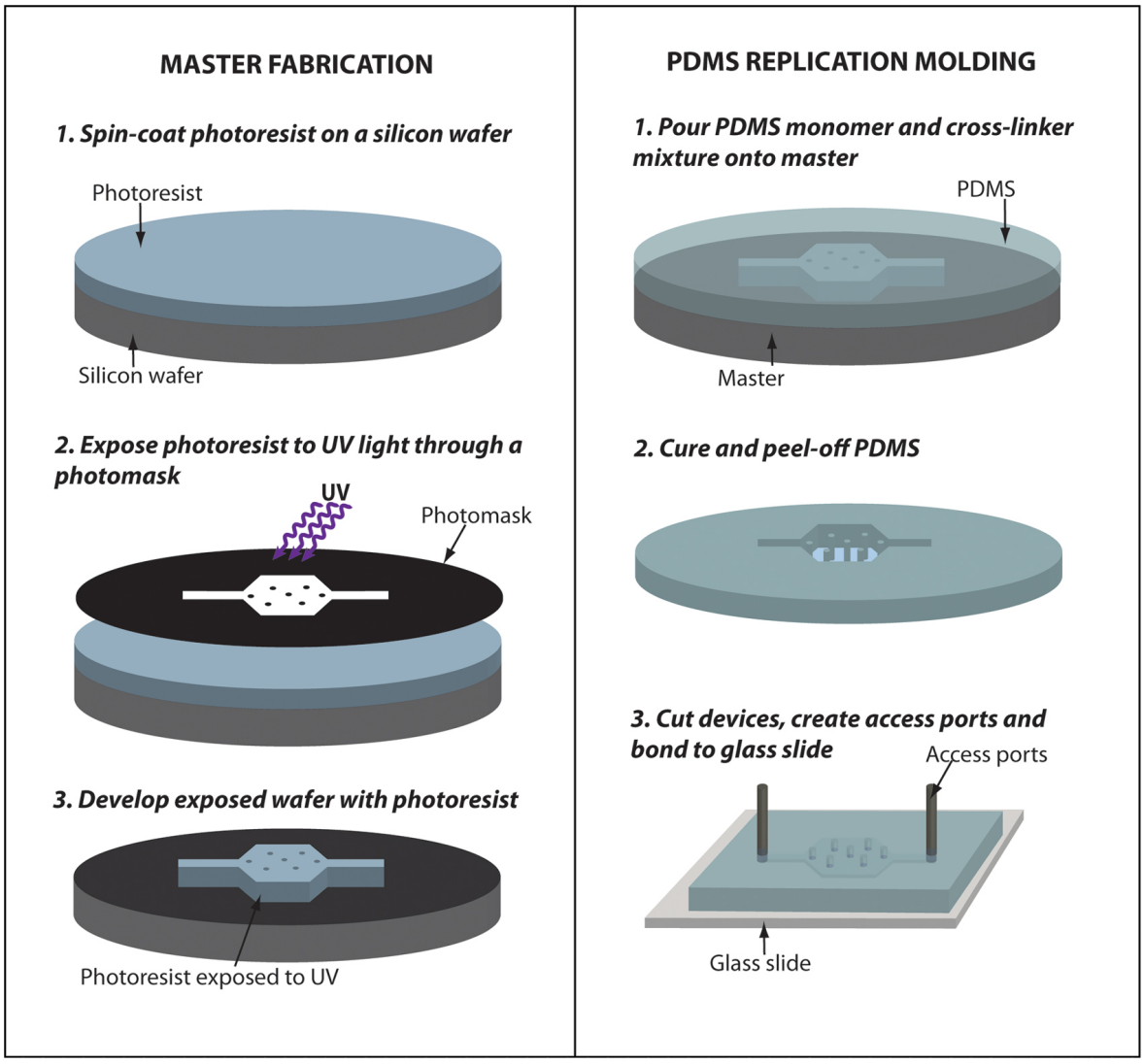

Figure 8: Photolithography Process [13]

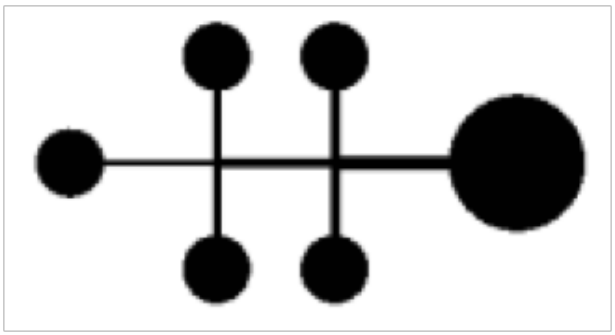

Figure 9: Our Photo–Mask (Color Inverted: Black allows UV light to pass through, White blocks UV)

MicroChem. This photoresist, however, is unable to attain thicknesses of much more than $100\,\mu\mathrm{m}$, due to its material properties. In an attempt to solve this problem, we switched to a similar photoresist, SU-8 2150, which should be able to attain thicknesses of $650\,\mu\mathrm{m}$ or more, giving us an acceptable aspect ratio for our channel [10]. SU-8 2150, however, because of its ability to produce very thick layers (at the edge of what is possible with photolithography), has problems developing cleanly and completely. Figure 10 shows the progress we have made thus far in adjusting the development procedure to maximize cleanliness and completeness of the development process. Shown are the improvements we have made, in chronological order, with our earliest prototypes (on the left, almost no development) up to our most recent prototype (on the right, with approximately 98% development), which likely would have been usable if it did not warp during storage between experimental steps. Unfortunately, we were not able to proceed further than this step by the termination of the Engaged Learning Project cycle, due to the long duration procedures associated with our photolithographic process. However, we will be continuing this research in the future, in order to manufacture and test hollow microspheres for electric field sensing applications.

6 Concluding Remarks

While we were unable to reach our end-goal of manufacturing and testing more accurate electric field sensors capable of detecting external inputs at greater frequencies, we have made significant progress toward this goal by attempting the two most promising manufacturing methods for producing hollow optical WGM micro–resonators, the latter of which still appears extremely promising with continued research. The progress made during this Engaged Learning Project is, without a doubt, and will continue to be, invaluable in making progress towards our goal of manufacturing better electric field sensors and, therefore, to the development of advanced prosthetic devices.

7 Acknowledgments

I would like to acknowledge Dr. Volkan Ötügen, my mentor; and Dr. Amir Ali; with whom I worked during part of my Engaged Learning Project, for their support and guidance, as well as the Engaged Learning Program, the Lyle School of Engineering, and SMU, for the financial support that made this research possible. I would also like to thank Dr. Enver Demirhan, whose knowledge of polymer chemistry was invaluable during the first half of my Engaged Learning Project. In addition, I would like to thank Dr. Melikhan Tanyeri for presenting his research concerning micro–fluidic devices at SMU, which inspired us to attempt a micro–fluidic solution to this problem. Finally, I would like to thank Dr. Ali Beskok and Dr. Can Sabuncu, as well as their graduate students, for sharing their laboratory's resources and patiently teaching me how to perform the soft–lithography process. Thank you for your support.

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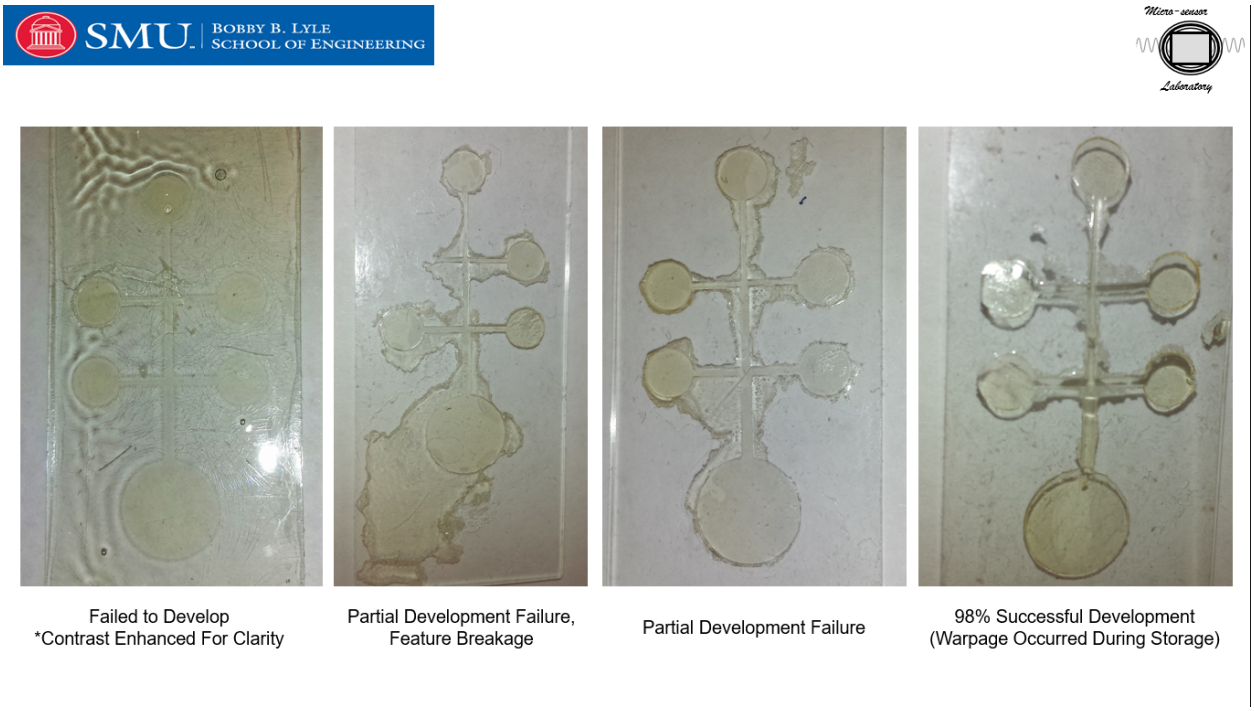

Figure 10: Progress in Photoresist Development

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