Volume 40 Fall 2020

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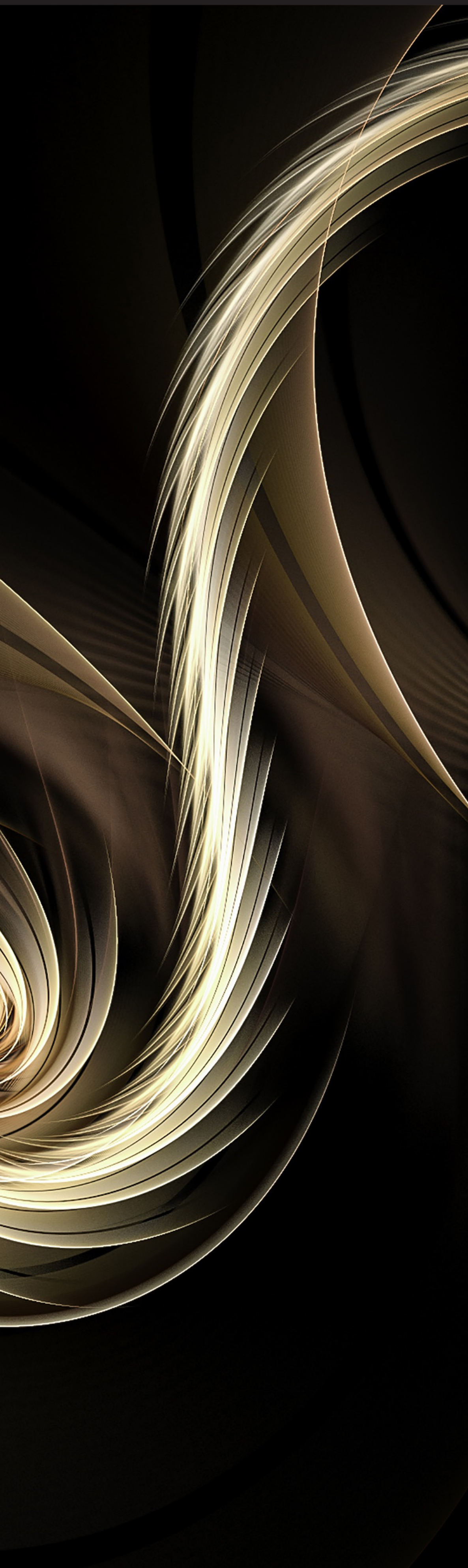

Contents

MURJ Staff
MIT Undergraduate Research Journal

Massachusetts Institute of Technology

January 2021

Dear MIT Community,

We are delighted to present the 40th issue of the MIT Undergraduate Research Journal, a biannual student-run publication that showcases undergraduate research on campus. As always, publication of this journal is a collaborative undertaking by an extraordinary team of dedicated students. In particular, we are indebted to the entire MURJ staff, for their patience, grace and flexibility as we all navigated the unprecedented challenges of a primarily virtual semester.

Over the past year, the COVID-19 pandemic has physically separated the MIT community. It is a testament to the dedication to undergraduate research at MIT, from the institution, mentors, and students themselves that in light of these challenges, an abundance of impactful research has continued. We are proud to showcase the hard work and creativity of MIT students to the world.

In this issue, we feature student reporting and research on a wide range of subjects—from an article on the ethics of biospecimen prices in the policy lab within the MIT Little Devices Lab to an in depth feature on how former students used their academic research to form the start-up Accion Systems and bring new technology to the space propulsion industry. Additionally we are excited to feature student work in linguistics, city planning, biology and mechanical engineering.

Finally, this magazine was assembled during a time of disregard for scientific facts, by some in the most powerful positions in government. We found hope and comfort in our peers' commit-

Massachusetts Institute of Technology

MURJ Staff
MIT Undergraduate Research Journal

ment to making the world a better place through the relentless pursuit of knowledge, its ethical application, and communication. It is by the example and mentorship of the current generation of scientists and engineers that many of the student contributors come to pursue their important work. We hope that you too are inspired and find reassurance in reading the work of these amazing students and scientists.

Best,

Natasha Joglekar
Co-Editor-in-Chief

Vaibhavi Shah
Co-Editor-in-Chief

For previous issues of the MIT Undergraduate Research Journal, please visit our website at murj.mit.edu. If you are interested in contributing to future issues of the MIT Undergraduate Research Journal, we would be delighted to have you join our team of authors and editors or submit your research for our Spring 2021 issue. Please contact murjofficers@mit.edu if you have any questions or comments.

Massachusetts Institute of Technology

UNDERGRADUATE RESEARCH JOURNAL
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PHYSICS

MIT's Little Devices Lab

Establishing a fair and ethical approach to obtaining samples for research, especially during outbreaks and within vulnerable communities, is essential.

The policy lab within MIT's Little Devices Lab researches different issues pertaining to bioethics, safety, and the usage of different biospecimens. Examining how human tissues and samples are used in research is essential in maintaining ethical and safe practices, especially during a pandemic. Throughout the summer, undergraduate researchers conducted remote research with the policy lab, seeking to find more information on a wide variety of subjects, with a specific focus on taking blood and tissue samples during disease outbreaks.

One specific research project conducted by UROP students in the Little Devices Lab regarded looking into blood samples and blood banks around the world. Each of our bodies hold and utilize blood for the entirety of our lives, which makes it an extremely valuable substance in medicine and scientific research applications. The UROP students looked to different periods of time where blood samples proved to be particularly valuable-- during times of disease outbreaks. Through literature searches, looking at news sources, and other methods, students found that during these outbreaks the value of blood is significantly increased. But this is also when the ethics of transferring blood from the patient to the science world becomes more questionable. Recently with Coronavirus (COVID-19), companies sold the blood containing antibodies of recovered patients for $40,000 per milliliter, showcasing the commercialization of samples to an extreme extent (1). Similarly, during the Ebola crisis in Africa, samples were taken from West Africa and distributed to different labs around the world. These samples certainly held a lot of value to researchers investigating the disease. However, researchers in the United States, France, and South Africa refused to disclose the number of samples they held, and restricted access to local scientists in Africa. Arising from this is the question: who do the samples actually belong to? With the blood samples, there was no consent given, and the samples could be tied to clinical or personal data. In Liberia specifically, the US took all of the blood samples for foreign research, leaving the citizens with nothing to benefit from (2). As the Little Devices Lab undergraduate researcher Alexandra Wolff said:

"Companies who sell bio specimens at such high profits are often profiting off the back of individuals who were unaware of the importance of the sample/bio specimens that they had. Often, these individuals are low-income, minorities, or from otherwise disadvantaged populations and are being taken advantage of by large corporations. In a system in which the corporations already have the power in terms of treatment and medicine, they are leveraging that power for further profits".

"Companies who sell bio specimens at such high profits are often profiting off the back of individuals who were unaware of the importance of the sample"

However, it is widely acknowledged that these samples are vital to research and curing of diseases. Without these samples, the world would be left without the ability to advance science and medicine, especially in critical times. Establishing a fair and ethical approach to obtaining samples for research, especially during outbreaks and within vulnerable communities, is essential. There is a definitive need for a balance between the rights of patients and the advances that can be made with research. Without one another, neither entity can succeed.

— Tatum Wilhelm

[Credit: Hu Chen via Unsplash]

MURJ Features

From the Lab to Infinity and Beyond: Accion Systems

MIT Department of Aeronautics and Astronautics

This issue's spotlight features Natalya Bailey and Louis Perna, Founders of Accion Systems

By Dinuri Rupasinghe

MIT is notable for aiding many students in their entrepreneurial endeavors, whether it be through seminars or by fostering conversations between students that turn into post graduation ventures. This is especially true for the many diverse STEM students who wish to turn their passion for research into a product or company. One notable team of MIT alumni has completed the daunting, yet exciting, journey from research to entrepreneurship.

Accion Systems is a propulsion system company that has pioneered an efficient ion thruster: the Tiled Ionic Liquid Electrospray (TILE). This small-satellite propulsion company was cofounded by MIT graduates Natalya Bailey and Louis Perna, with the help and technical expertise of Professor Paulo Lozano at MIT's Space Propulsion Laboratory. Natalya Bailey graduated from MIT with a PhD in Aeronautics and Astronautics in 2015, after attaining a master's degree in Mechanical Engineering at Duke University. She is the current Chief Technology Officer of Accion Systems and a lifelong rocket enthusiast.

Louis Perna graduated from MIT after obtaining an undergraduate degree in Aerospace Engineering and finishing a Master of Science in Aeronautics and Astronautics in 2014. He is currently Chief Scientist at Accion Systems, and I had the pleasure of speaking to him about his transition from academia to Accion Systems.

Accion Systems mission is to redefine the performance, efficiency, and scalability of spacecraft propulsion systems to expand what's possible in space. [Credit: Accion Systems]

Their journey started when Bailey, Perna, and Professor Lozano collaborated at SPL. Perna met Professor Lozano while exploring options for his course 16 capstone project. He and his project partner chose to do a project on electrospray, testing colloid thrusters at high pressures. Thrusters are propulsion systems that can change the movement of a satellite in space. Colloid thrusters, specifically, are thrusters where charged liquid droplets are used to produce such thrust. After this research, Perna became further fascinated with propulsion and aerospace engineering and decided to pursue an advanced degree in propulsion.

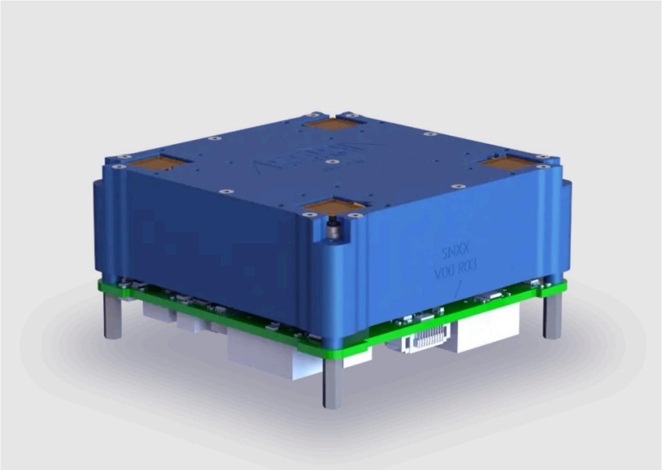
Perna had stepped in line to hand in his registration papers for graduate school at MIT, when he recognized someone who he had connected with through emails: he fatefully met his future co-founder and CTO, Natalya Bailey.

The two of them would be doing work at MIT's Space Propulsion Laboratory. Fortunately, the propulsion technology of the late 2000s and early 2010s at the SPL was implementable, manufacturable, and had high potential. Perna notes, "Companies started coming to the lab asking to fly [the propulsion technology] on their satellite… that was a signal to Natalya and Professor Lozano that there was a business opportunity here."

Accion Systems' innovative TILE propulsion system held countless attractive technical attributes that fueled such entrepreneurial enthusiasm. Commonly, there are two main categories of propulsion systems: chemical and electrical. Chemical reactions are what you'd typically think about when envisioning rockets - fiery orange blasts of combustion reactions making a rocket charge through space. On the other hand, there are electrical interactions which take advantage of electrical potential energy, which is the energy stored in a particle when put into an electric or magnetic field. It produces quiet spontaneous interactions to propel a satellite forward, which Accion's thrusters take advantage of.

Perna explains, "The major benefit to electric propulsion is that you can make the particles go much faster. You can think of the automobile equivalent as miles per gallon. Your space shuttle main engine, while it's an awesome engine, is more like a semi truck or a tank. It doesn't get great mileage, but it can work really hard… Electric thrusters are more like a hybrid or something even more efficient, where you're getting a lot of distance out of your fuel but you can't tow as much or you can't go as fast." Hence, TILE engines have incredible specific impulse, which is a measure of how efficiently the thrusters utilize their propellant. However, the thrust produced is lower than others. As a result, Accion focuses on aiding small satellites with propulsion in space since their TILE engine allows for efficiency, accuracy in movement, safety, and most importantly, capability, for smaller loads in space.

Accion Systems specializes in their ionic liquid electrospray, otherwise known as their electrostatic thrusters. Since the electrospray utilizes a liquid propellant, there is no need to convert the propellant into plasma, or an ocean of charged particles, because it is already conductive and can be directly evaporated and accelerated. Perna compared this phenomenon to dissociation of ions in spontaneous reactions. When you drop table salt, NaCl, in a glass of water, the ionic compound spontaneously separates into its two component ions, Na+ and Cl-. Similarly, Accion's liquid electrosprays are entirely composed of ions, meaning that the salts are essentially liquid rather than solid. Perna clarifies, "In fact, ionic liquids are commonly called room-temperature molten salts." Such characteristics of the liquid propellant are advantageous because in typical electric propulsion systems, the gas propellant must be converted to plasma before its extraction and acceleration.



TILE-2 Propulsion and attitude control small enough for CubeSats, and flexible enough for larger satellites.[Credit: Accion Systems]

Accion also follows a microfabrication approach to their thrusters. Each "thruster" is composed of tiny cones that release a controlled flow of propellant to produce thrust. This enables extreme precision in their designs and controls the flow of the liquid propellant mass better. Accion can also build thrusters in any size - all they have to do is add more tiny thruster cones accordingly. Perna comments, “Electrospray presents a very scalable capability. We can make a thruster that fits on a satellite the size of your smartphone or smaller or we can add more and more sources all the way up to a starship that SpaceX is building”.

"We were trying to do things very differently from what others were doing."

Evidently, in 2012, the Accion team had innovative technology and plenty of people were interested in it. However, the decision to leave MIT was difficult. Perna reflects on his days at MIT as an undergraduate and graduate student: he believes the MIT PhD program was an amazing opportunity, but his team saw potential in the TILE system they had fine tuned over the years at SPL.

There were both pros and cons of leaving MIT for Accion's start up adventure. At MIT, the team had access to student support resources and could find easier ways to fund their projects. Perna also expresses admiration for his time at MIT, noting, “I do miss grad school, it's always a fun time to not only be doing the research but taking classes at the same time that are helping you understand what you're researching.”

Additionally, pursuing research in an area that very little people have explored, such as electrosprays, can be difficult. Perna explains, “What we were doing was definitely very difficult. It was dissimilar to what a lot of people had done before, which is a great thing to say about your research. You want to be doing something new, unique and exciting. What comes along with that is that there's not always an option to go look at a paper or read a textbook or call somebody out in the world, whether it be at another institution or at a company and say ‘Hey, how did you solve this problem, because I'm doing something extremely similar.’ We were trying to do things very differently from what others were doing.”

As a result, the company had to use testing and iteration to perfect their technology.

Perna also mentioned a distinction between doing research at an academic institution and working on a start up: in research, your goal is to discover something new to bring to the world. At a startup, you must work towards selling a product that is “knowable, tested, and provable”. If a student were to follow in Accion Systems’ footsteps, they must understand the difference between these two institutions, and understand when their technology is adequate enough to bring to the public market. They must also focus on customer interaction, managing people, and setting up equipment and testing.

Despite the countless iterations of testing that Perna and the Accion Systems team faced, their TILE engine has definitely made a splash in the world of propulsion systems. TILE 2 and TILE 3 are set to launch on multiple vehicles in 2021. TILE 3, a product part of NASA’s Tipping Point program, is a product in the works with twice the size and ten times the capability of their previous thrusters. Accion Systems is currently targeting to increase the reliability, longevity, and density of their thrusters.

Lastly, Perna left off with a message for students: “Enjoy your time at MIT. I had a lot of fun as both an undergraduate and graduate student. I wish I could transport back in time to do it all over again. It’s a lot of hard work, but it’s definitely worth it.” If you are an MIT student interested in working on undergraduate research at the Space Propulsion Laboratory, Perna urges you to go meet Professor Lozano and attempt a project: “There’s plenty of opportunity there to become a rocket scientist.”

A New Way to Stimulate Neurons

MIT Department of Brain & Cognitive Sciences

Treating Parkinson's Disease by mechanically stimulating neurons using magnetic nanodiscs

By Melbourne Tang

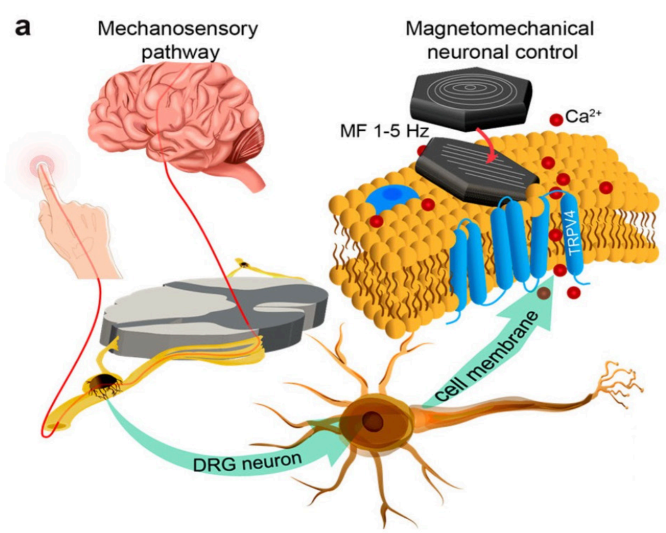
According to the Parkinson's Foundation, more than ten million people worldwide suffer from Parkinson's disease. While there is no cure and most treatments are minimally effective, electrically based neurostimulation has shown potential in treating Parkinson's disease and other conditions.

Recently, another door to improved treatments has been opened by a team of researchers that includes former postdoc Danijela Gregurec, Alexander Senko PhD '19, and Associate Professor Polina Anikeeva. They have developed a method to mechanically stimulate neurons using magnetic nanodiscs. This idea might be useful in not only providing therapeutic treatments, but also better understanding neural pathways.

This new way of stimulation differs from existing techniques that rely on chemical or electrical pathways. No pharmaceuticals or wires are involved, so it is minimally invasive. Due to the body's low magnetic permeability and conductivity, using magnetic materials allows for targeted and controllable stimulation. Magnetite nanoparticles have long been used as cell-tracking agents for MRI and in other biomedical applications. Thus, according to Anikeeva, they were natural candidates for the magnetic nanodiscs that the group wanted to create.

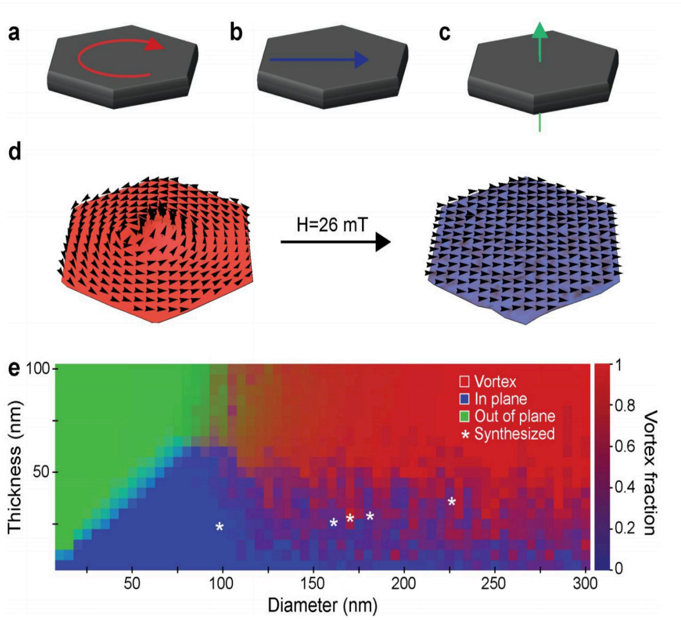
Both the size and special vortex configuration of the magnetic nanodisc offer advantageous features. Currently, magnetic tweezers are used to study the mechanical properties of macromolecules, such as DNA, (on the scale of micrometers) in single-molecule experiments. Stimulating neurons, on the other hand, calls for smaller tools to manipulate nanoscale ion channels in vivo. Therefore, magnetic nanoparticles are safer and more practical for studying neural activity in live animals.

In addition, inciting reponses in neural cells requires relatively large forces in the piconewton range. (For reference, one piconewton is "about the weight of a red blood cell" or "approximately the force exerted by a standard laser pointer on a screen" (Yusko and Asbury, 2014). Such forces are typically produced by permanent magnets, but this makes it challenging to control the force exerted. To combat this, the team turned to magnetic vortices, which have near zero magnetization in the absence of a magnetic field. Thus, they are



Magnetomechanical stimulation of MND-decorated DRG neurons allows for remote activation of Ca2+ influx. Used with permission from [2].

relatively more stable when suspended in solution and have the potential to safely remain in the body. When a small magnetic field is applied, the magnetic spins realign with the magnetic field and the disc acts like a lever to generate the torque needed.



The magnetic vortex phase in magnetite nanodiscs. Used with permission from [2].

Magnetic vortices are prevalent in the data storage community, and the researchers translated this idea to physiological applications. Anikeeva, who completed her graduate studies quantum dot and organic LEDs (QLEDs and OLEDs), shifted her career to neuroscience in hopes of uncovering some of the many mysteries about the brain.

Anikeeva and her fellow researchers have added to the toolkit for controlling ion channels. Y. Eva Tan Professor of Neurotechnology Ed Boyden, whose group conducts research in using light to measure and control brain activity, remarks that this work "seems like a very nice use of fundamental physics and materials science to make a new modality of neuronal and cellular control!" This paper was a proof of principle: electron holography confirmed the vortex configuration of the magnetic nanodiscs, and using them to stimulate calcium influx activated sensory neurons from the dorsal root ganglia. The next steps include applying them in vivo. Questions remain about safety and efficacy. For instance, delivering the magnetic nanodiscs to control the appropriate ion channel requires membrane targeting. Nonetheless, this advancement provides a path to better understanding of mechanically activated neural cells, more effective treatments of neurological conditions, and even modulating the function of mechanically-sensitive organs, says Anikeeva.

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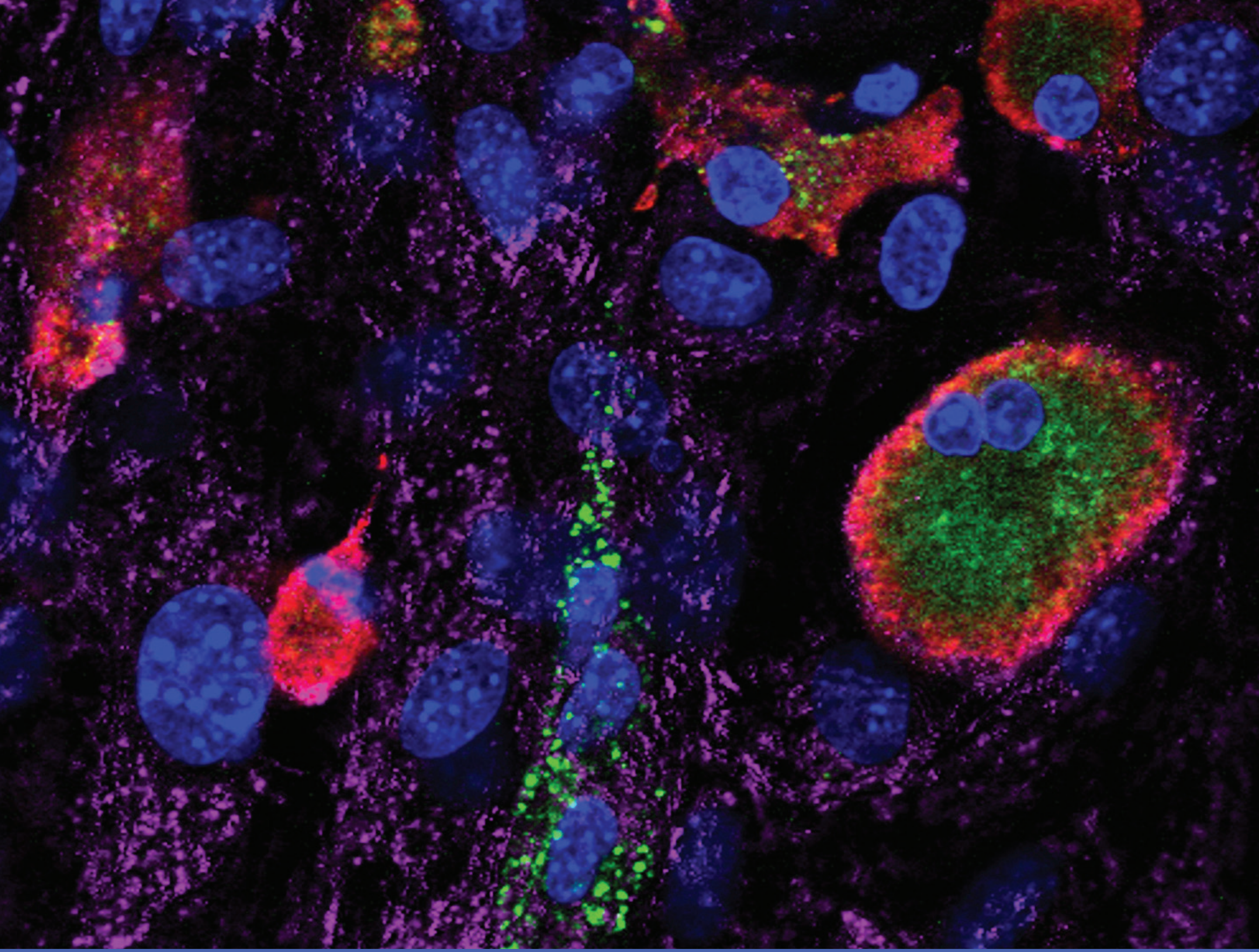

MURJ UROP Summaries

Understanding Programmed mRNA Decay in *B. subtilis*

Wilson Gomarga[1], Matthew Tien[2], Gene-Wei Li[3]

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3 Principal Investigator, MIT Department of Biology, Cambridge, MA 02139

1. Introduction

In prokaryotes, mRNA transcripts under a single promoter express their multiple-encoded proteins in distinct stoichiometries with high precision (Madigan et. al, 2014, Lalanne et. al, 2018). One mechanism that allows for differential protein expression from a singularly transcribed multi-gene operon is RNA degradation (Dar & Sorek, 2018) (Figure 1). Although transcriptional regulation encapsulates much of what we know of gene expression, post-transcriptional regulation, such as RNA degradation remain a facet of the central dogma that is not well understood. In my time in Gene-Wei Li's Lab, I uncovered evidence that RNA degradation pathways in *B. subtilis* interplay with ribosome initiation dynamics. Despite the variable spacing between the Shine-Dalgarno sequence (ribosome-binding site) and start codon (Wakabayashi et al., 2020), I observed consistently the presence of many mRNA isoforms that start at 11 nucleotides upstream of start codon.

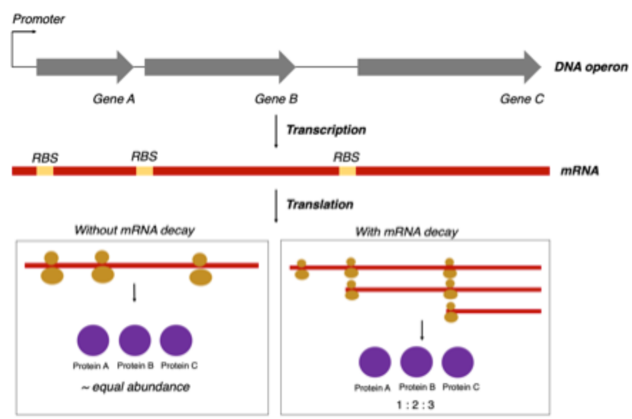

Figure 1. Programmed mRNA decay allows for multi-gene operons to be produced with distinct stoichiometries. Post-transcriptional processes such as RNA decay can allow for complex transcripts to produce distinct and precise protein stoichiometries (Concept adapted from Dar & Sorek, 2018)

2. Results & Discussion

A recently developed technique in the Li Lab called end-enriched RNA sequencing (Rend-Seq) allows for precise 5' and 3' ends mapping of RNAs and quantification of their abundances (Lalanne et. al, 2018) (Figure 2A). Combining this technique with time-resolved transcriptional shutdown experiments, I observed how RNA ends change over time with single-nucleotide resolution. Rend-seq data from *B. subtilis* treated with a transcription inhibitor (*rifampicin*) revealed evidence of highly stabilized fragments of mRNA at 11 nucleotides upstream (-11) of the start codon in a time-dependent manner (Figure 2B). Based on this observation, I generated testable hypothesizes that could explain the emergence of these elusive rifampicin-dependent peaks and how they are signatures of a specific RNA degradation pathway.

Genes with -11 peaks have almost twice the protein synthesis rate. Comparing ribosome foot-printing data with genes with -11 peaks, many genes in this class have twice the translational efficiency and lower average half-life compared to the genes without -11 peaks (Figure 2C). Interestingly, many of them encode for translational proteins. A sequence motif analysis of these peaks reveal that they occur right downstream or within the Shine-Dalgarno (ribosome binding site) sequence (Figure 3A). Based on these several observations, I propose two models to explain this phenomenon (Figure 3B).

First, these peaks could arise from endonuclease cleavage at a specific site within the Shine-Dalgarno motif. However, this is unlikely because SD sequences found throughout all mRNAs do not display evidence of cleavage. In addition, the peak positions are not consistently placed within the motif (some are shifted by 1 or 2 nucleotides). Alternatively, an endonuclease cleavage event could occur further upstream of the mRNA, allowing for an exonuclease to digest the leader until it is hindered sterically by a ribosome bound to the start codon. This occlusion could cause accumulation of RNA ends at the start codon. This model accounts for the differing stabilized position within the Shine-Dalgarno motif associated with the peak.

RNase Y is the central endonuclease in *B. subtilis* (Lehnik-Habrink, 2011). Therefore, it would be informative to see the effect of RNase Y knock-down on the presence of -11 peaks. Interestingly, Rend-Seq data from RNase Y depleted mutants treated with rifampicin do not show presence of -11 peaks, confirming the model that RNAse Y plays a role in the emergence of these peaks. Next, further work can be done to answer where the endonucleolytic cut happens. Given that endonuclease substrate recognition in bacteria is not well-defined, this UROP on RNase Y will provide illuminating insights to the initiation of RNA decay in prokaryotic systems.

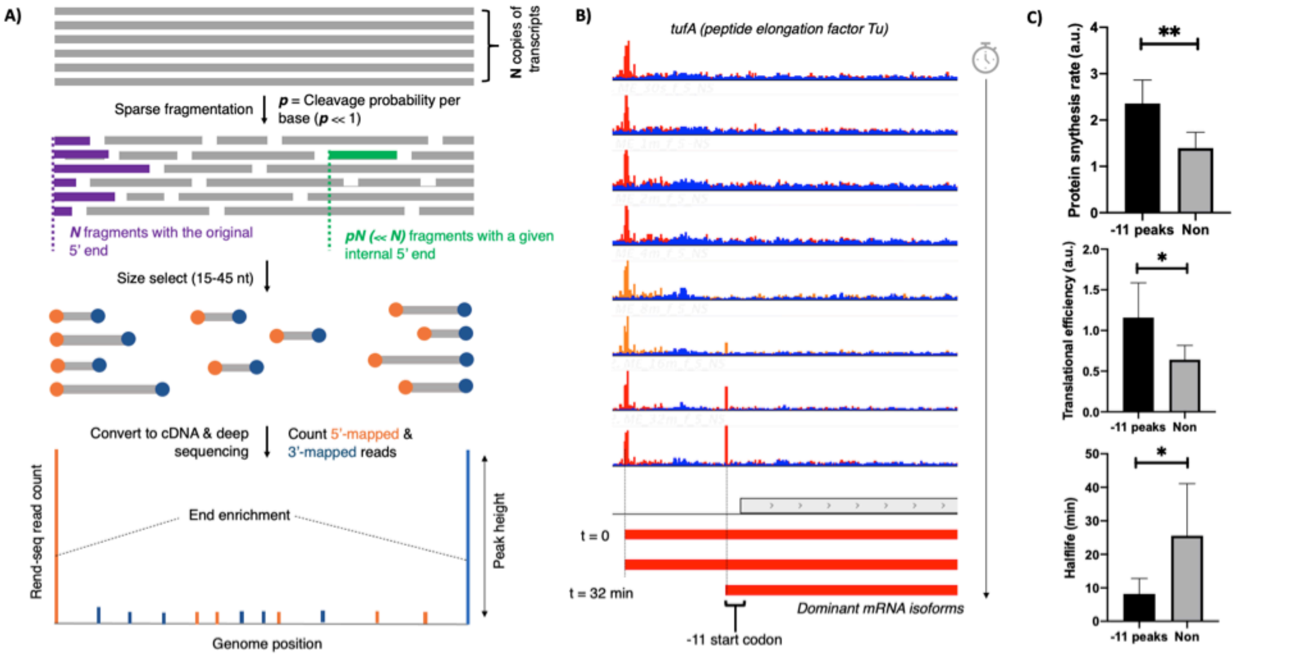

Figure 2. Stabilized mRNA isoform with 5'end at 11 nucleotide upstream of start codon (-11 peaks). (A) Schematic of Rend-Seq (adapted from Lalanne et al, 2018). (B) Rend-Seq data from B. subtilis from 0, 1, 2, 4, 6, 8, 16, 32 mins after rifampicin addition. (C) Comparison of genes with and without -11 peaks. (Student's t-test, n = 95, 67, 60 [top-bottom], mean ± 95% CI, *p<0.05, **p<0.005)

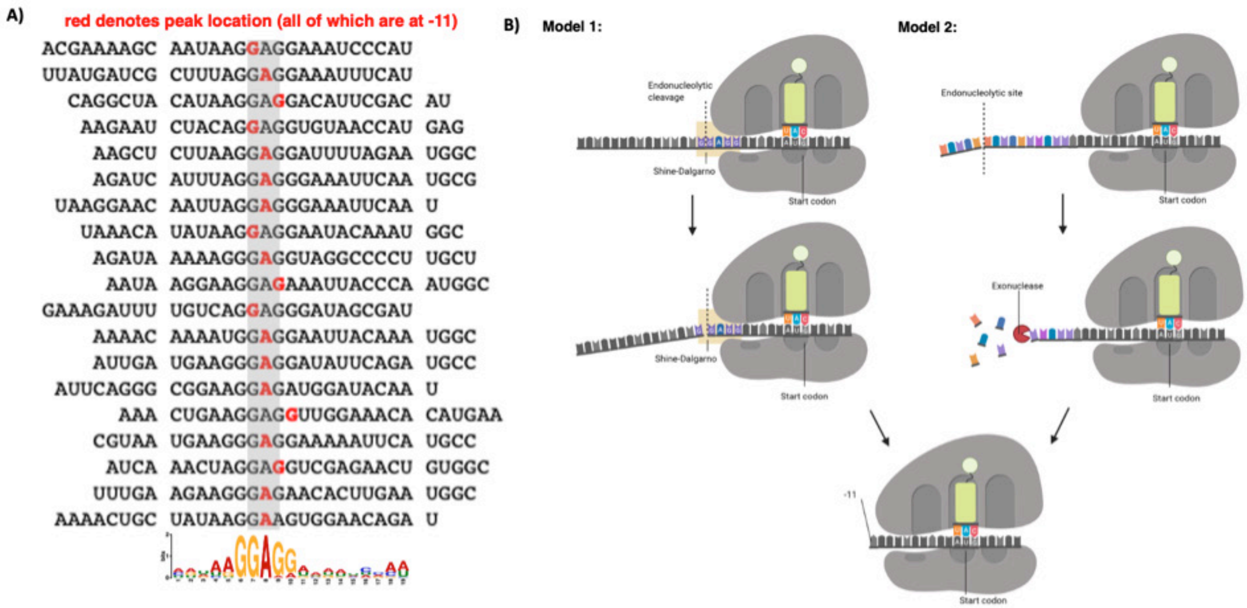

Figure 3. Two models to explain the presence stabilized -11 peaks. (A) Motif analysis of 19 representative peaks at -11 (E-value = 4.5e-16). GGAGG sequence denotes Shine-Dalgarno motif. (B) Model 1: Endonucleolytic cleavage happens within the Shine-Dalgarno motif sequence. Model 2: Endonucleolytic cleavage happens further upstream, followed by exonuclease cleavage. Ribosome serves as a steric hindrance, preventing exonuclease from chewing further off the mRNA strand.

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Comparison of COVID-19 Innovation Between the United States, Europe, and China

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1. Background

We sought to determine which region, People's Republic of China (China), the United States of America (US) or Europe (as defined by the World Health Organization) (WHO, 2020) has been more "innovative" during the COVID-19 epidemic over time, as measured by searching the full content of peer-reviewed scholarly work on COVID-19 produced from January to November 2020.

2. Methodology

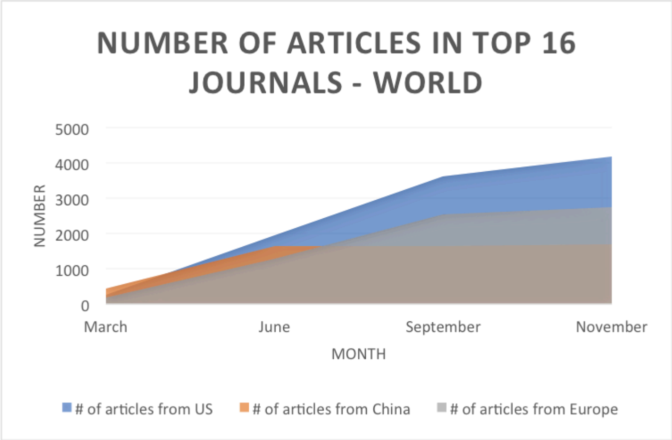
We analyzed the iSearch COVID-19 platform (NIH's comprehensive, expert-curated source for publications and preprints related to either COVID-19 or the novel coronavirus SARS-CoV-2) for research articles in several key categories and subcategories from January to November (NIH, 2020). All COVID-related research articles were sorted by country of origin at 4 time points (the last date of March, June, September and November). US, European and Chinese (including Hong Kong and Macau) institutions were separated while all remaining countries were designated as "Other." These research articles were further filtered by publication in the 16 top medical journals worldwide by highest H-index, excluding non-medical journals (Nature, Science, Cell, Lancet, PNAS, JAMA, Nature Medicine, Clinical Infectious Disease, Clinical Virology, Medical Virology, European Respiratory Journal, Lancet Infectious Disease, Lancet Respiratory Medicine, Critical Care, Infection, Head and Neck) (SJR, 2020).

Research articles were divided based on 3 clinically relevant categories: Therapeutics (Remdesivir, Methylprednisolone), non-Therapeutics (Swabs, Masks) and Biological Mechanisms of Action (Oxygen, ACE-2, Immunoglobulins, D-Dimer). Non-research articles, such as Reviews, Editorials, Personal Narrative, Case Reports, News and Practice Guidelines were excluded from this analysis.

A full list of institutions of primary author affiliations for each article was imported into Google Sheets, and the number of articles indexed to each primary institution was recorded. Each institution was categorized by country of origin through ezGeocoding (https://geocode.ez34.net/), and total number of publications per country was calculated. Linear regression and normalization was performed in Microsoft Excel (Version 2020). Population data was aggregated from the World Bank (World Bank, 2020). Number of articles per citizen calculation was a calculated average from the 4 timepoints during the pandemic.

3. Results & Conclusions

The total number of articles in the Top T16 journals until the end of March was 1,065, June was 5,725, September was 9,100 and November was 10,011. The number of articles published by Chinese researchers were initially 69% greater than the United States and 45% greater than Europe; they were narrowly overtaken in June (19%) by the United States, a deficit which expanded by September (118%) when Europe also overtook China (52%) (Figure 1). By November, the US had the greatest number of research articles, followed by Europe and then China. Number of research articles closely follow each nation's respective patient



Time Period, from January to	Number of Articles US	Number of Articles China	Number of articles Europe
March	255	431	175
June	1954	1634	1283
September	3,623	1,655	2529
November	4173	1693	2744

Figure 1. Total number of COVID-related articles from Top 16 global journals (T16) at 4 time points during the COVID-19 pandemic. Published research from China was overtaken by the US in June and Europe in September.

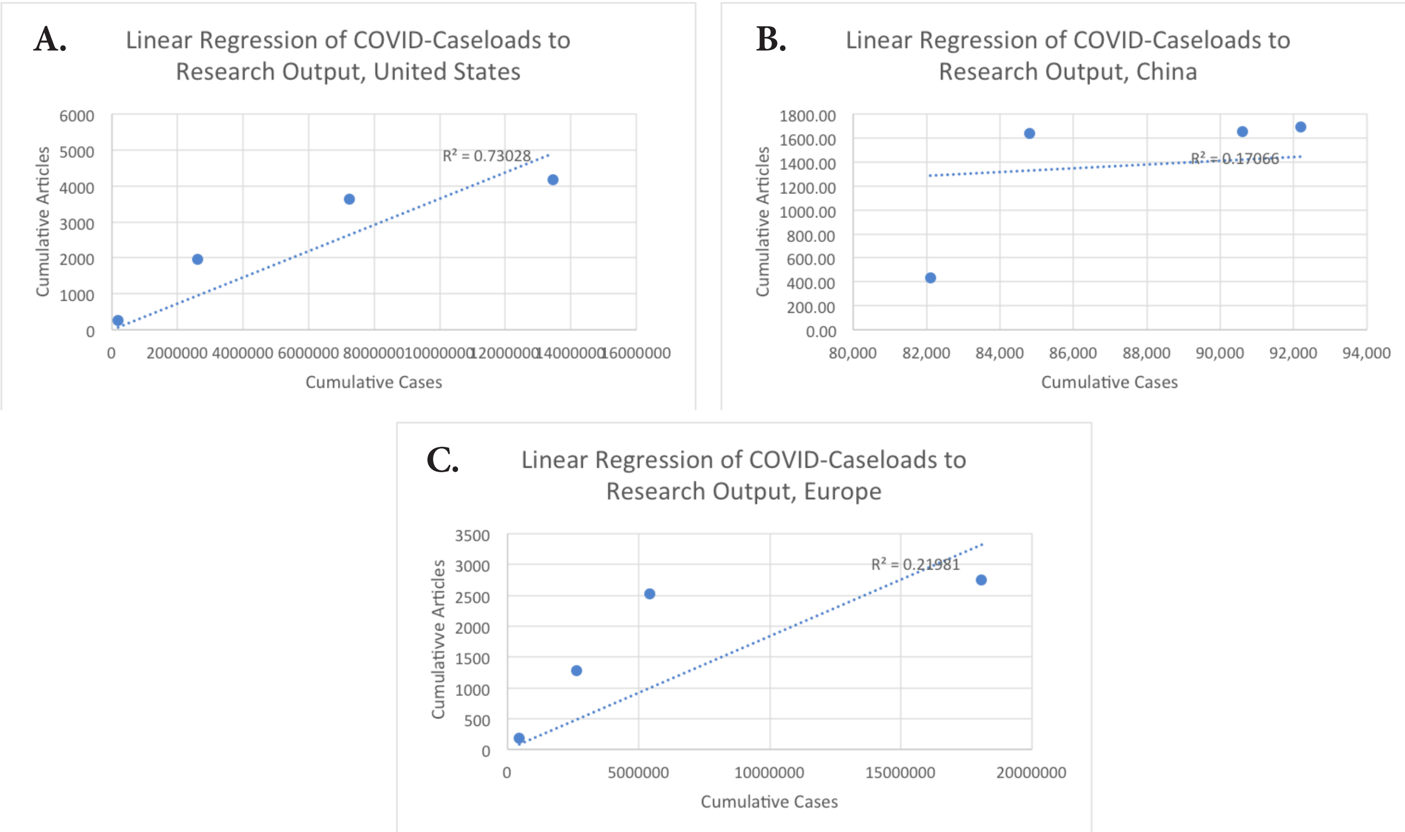


Figure 2. Linear regression showing correlation between research output and caseloads for different regions. (a) US has the strongest correlation (r2 = 0.93), followed by (b) China (r2 = 0.89) and (c) Europe, (r2 = 0.79).

loads (r2 = 0.93, China; r2 = 0.89, US; r2 = 0.79, Europe) (Figure 2). High research output correlated with China's first quarter caseload peak, followed by the second and third quarter peaks in the United States and Europe. (Institute for Health Metrics, 2020). After normalization of total articles over the past 11 months with population, the US held a greater average research output per citizen (7.6 articles per million citizens), followed by Europe (3.76 articles per million citizens) and China (0.96 articles per million citizens) (Figure 3).

Research articles focusing on therapeutics, specifically the two only clinically proven medications for COVID-19, Methylprednisolone and Remdesivir, remained dominated by Chinese authors in T16 Journals worldwide during the first half of the pandemic, after which US authors gained the lead (Figure 4a). In non-therapeutic technologies, Chinese researchers published more articles during the early stages of the pandemic. European authors however overtook both the US and China by June. (Figure 4b). In basic science mechanism of action categories, Chinese investigators published more research articles during the period of this study, until November. In specific areas of research, ACE-2 and Immunoglobulins, US authors had more publications than Chinese or European counterparts by June and widened their lead by September (Figure 4c).

Our study has limitations as the journals included in our analysis were all English-language; we expect COVID-19 publications in native Chinese and European journals, however as they were not PubMed based, they could not be analyzed. Other research vehicles, including patents, drug discovery and clinical trials, were not included in this study and could be useful in comparing innovation between countries.

Our study shows a clear pattern of all three major world players accelerating COVID research output coinciding with periods when their respective caseloads are high. The United States showed the greatest research output per citizen overall, followed by Europe and then China. Each nation has specific areas of research where they have the strongest overall output, non-Therapeutics for European authors, Therapeutics for US and Biological Mechanisms of Action for Chinese authors. Despite China's new entrance into the global research landscape, they have taken a competitive position in COVID research during the pandemic and lead innovation in key clinical categories.

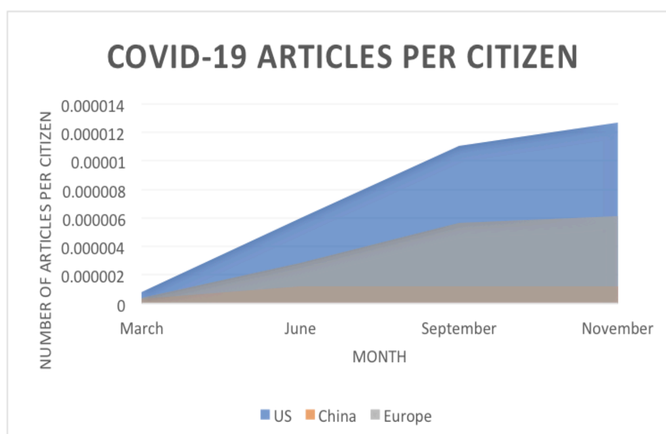
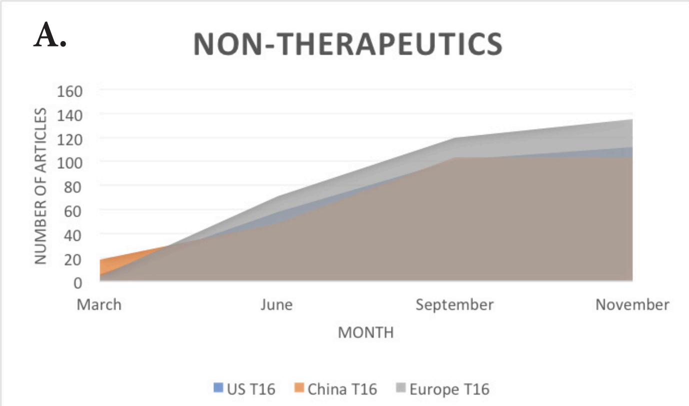
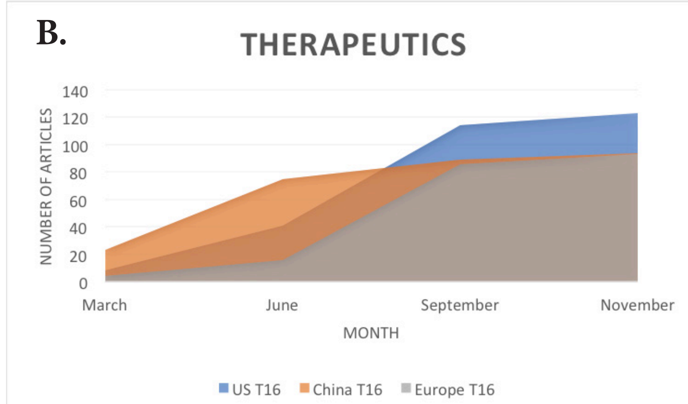


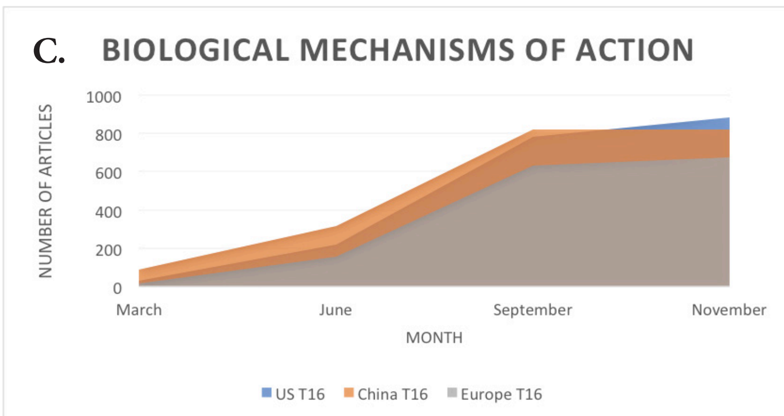
Figure 3. Normalization of total COVID-related research based on population of different regions. US had the greatest number of articles per citizen during the pandemic.



Time Period, from January to	Number of Articles US	Number of Articles China	Number of articles Europe
March	6	18	4
June	58	48	71
September	101	103	120
November	112	103	135



Time Period, from January to	Number of Articles US	Number of Articles China	Number of articles Europe
March	8	23	4
June	41	75	16
September	114	89	86
November	123	94	93



Time Period, from January to	Number of Articles US	Number of Articles China	Number of articles Europe
March	28	87	14
June	220	318	154
September	780	820	633
November	883	822	675

Figure 4. Linear regression showing correlation between research output and caseloads for different regions. (A) US has the strongest correlation (r2 = 0.93), followed by (B) China (r2 = 0.89) and (C) Europe, (r2 = 0.79).

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Third Language Acquisition of Relative Clause Structures in Hindi

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This paper investigates the acquisition of three types of relative clauses (1 – 3 below) in Hindi by 16 participants with L1 Marathi (SOV), L2 English (SVO). The question asked is whether the patterns of acquisition of Hindi as a third language matches those isolated in rst language acquisition of the same relative clause structures in English, French, Tulu, Korean and Chinese (See Lust, 2006). That is, we investigate whether there is a primacy of the free relative clause in the acquisition of these complex structures.

Marathi and Hindi both share SOV word order (as well as the Devanagari script), while English has an SV O word order. The Marathi language has three grammatical genders (masculine, feminine and neuter) while Hindi has the rst two. Marathi also employs agglutinative, in ectional and analytical forms, and the use of inclusive and exclusive forms of "we". Marathi also follows a split-ergative pattern of verb agreement and case marking—being ergative in constructions with perfective transitive verbs or obligative verbs, and nominative elsewhere. Despite being an Indo-Aryan language like Hindi, numerous Dravidian linguistic patterns have been found in Marathi.

An elicited imitation task was administered to participants (beginner to intermediate) in Hindi. Participants repeated verbatim 12 exemplars each of sentences 1 – 3, systematically controlled for the number of words and syllables.

1. Semantically specified (head NP with semantic content):

   The student who called the gentlemen answered the policeman.

   सज्जन को फोन करने वाले छात्र ने पुलिसवाले को जवाब दिया।

2. Semantically unspecified (head NP without semantic content):

   The person who introduced the doctor informed the lawyer.

   डॉक्टर का परिचय कराने वाले व्यक्ति ने वकील को सूचित किया।

3. Free Relative (head NP not lexically speci ed):

   Whoever greeted the gentleman informed the engineer.

   सज्जन को अभिवादन करने वाले ने इंजीनियर को जानकारी दी।

Results indicate that the participants imitated sentences in 3 (mean 6.7) signi cantly more successfully than either 1 (mean 4.83, P = 0.017) or 2 (mean 6.33, P = 0.007); there was no signi cant di erence between the correctness of sentences in 2 and 3. These results suggest the primacy for the free relative in acquisition. Additionally, results of the error analyses indicate that sentences in 1 and 2 were converted to sentences in 3, but never vice-versa.

Results suggest that in developing the language-specific grammar of Hindi as in the other languages noted above, there is a primacy of the free relative clause. The free relative is hypothesized to provide a transparent mapping for the construction of lexically headed relative clauses. We suggest that the developmental primacy of the free relatives re ects a interaction between semantics and syntax in the developmental course of acquisition. Free relatives provide a more direct map to the semantics, and at the same time, they o er syntactic evidence the learner can draw upon in constructing lexically headed forms in the target language (see Flynn, 2004 p 59). It is important to note that in spite of the di erences in languages and acquisitional processes, e.g., varying L1, L2, and L3, we observe astoundingly similar universal patterns of acquisition.

Our analysis permits a united explanation of the developmental trend across L1 and L3 acquisition while also providing a way to approach the problem of development over time within a rationalist model for acquisition. Our analysis explains development over time, because for any learner, it will take time to discover the unique way the target language lexically represents the abstract components of syntax, and to discover how these components interact in relative clause structures (see Flynn, 2004 p 68; Lust, 2010).

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MURJ Reports

Space and Media

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Introduction: An American Family

September 13, 1962. In a house not unlike any other, Jimmy's dad reads the morning news to his son. Today, President Kennedy remarks on the space challenge at Rice University.

> *I am delighted to be here and I'm particularly delighted to be here on this occasion... For we meet in an hour of change and challenge; in a decade of hope and fear... Surely the opening vistas of space promise high costs and hardships as well as high reward. So it is not surprising that some would have us stay where we are a little longer, to rest, to wait. But this city of Houston, this country of the United States was not built by those who waited and rested and wished to look behind them. This country was conquered by those who move forward and so will space... We choose to go to the moon in this decade, and do the other things — not because they are easy, but because they are hard… (Kennedy, 1962)*

Seven years later and three days before a giant leap for mankind, Neil Armstrong, Michael Collins, and Buzz Aldrin are halfway to the moon, stuck in the Command Module — a tight gray metal container with hundreds of buttons and thousands of potential problems that could result in t he loss of their lives and the forfeiture of American hope. They're moving at 4963 mph, fast enough to go from New York to California in 30 minutes.

Neil Armstrong pulls out the camera from the designated spot in the crowded compartment. It floats and spins, now no heavier than a soap bubble. Neil finally takes control of the camera and points it towards home.

At the same time on Earth, Jimmy's parents gather the family in the living room around every American's favorite new toy. It's called a television. Lately, it has been showing news like "Civil rights protesters assaulted by local Alabama police", and "Vietnamese civilians casualties in war", but today, within the television set lies the sight of our shared planet. Something within them pulls Jimmy's family towards the unseen. They smile in awe at the blurry blue ball with splotches of white and green surrounded by the vast, black void of space. The scale of the motion picture is incomprehensible. It's just a few pixels, yet contained within them is the near total sum of humanity — all of its beauty and struggle and creations.

Two decades prior, World War II had ended and the United States was starting to define itself as a global superpower.

How did this space mission become so fundamental to the American public?

Big Science

When students go to class, they learn about the great monuments built by ancient civilizations. They learn about The Colosseum in Rome, built for spectacles with gladiators and other cultural traditions. They learn about the Parthenon in Greece, erected so Athena would have a place to rest and bless the nearby populations with good fortune.

When future students go to class, they will learn about our monuments to power and greatness, which have come to be more technology-centric. They will judge our modern civilization, not by the conquering of nations, but by our conquering of physics. Alvin M. Weinberg (1961) explains this in an article for Science titled "Impact of Large-Scale Science on the United States". He says:

> *When history looks at the 20th century, she will see science and technology as its theme; she will find in the monuments of Big Science— the huge rockets, the high energy accelerators, the high-flux research reactors— symbols of our time just as surely as she finds in Notre Dame a symbol of the Middle Ages. She might even see analogies between our motivations for building these tools of giant science and the motivations of the church builders and the pyramid builders (p. 161)*

In order to understand how the space race was funded, let's look at how science was funded prior to NASA's founding, and how it led to Big Science.

At the beginning of the scientific revolution in the 16th century, most research was financed through wealthy individuals' patronage, or through personal funds. Since scientists mostly depended on the support of their patrons or their own personal funds, there was a strong incentive for the outcome of some of their experiments to apply to the patrons' interests. Most of these scientists also worked primarily alone, only interacting with others to critique work and garner data. As an example, Johannes Kepler, one of the most prominent astronomers of the 16th century, survived on teacher appointments until he found the patronage of Tycho Brahe, a Danish nobleman and fellow astronomer. Tycho provided a place to live and enough money for Kepler to be able to continue his research. After Tycho's death, Kepler became the imperial mathematician to Emperor Rudolph II. In order to please his new patron, he spent a significant amount of time writing horoscopes for him and named his most prominent work of the time "Rudolphine tables" (Caspar, 1993, p.85-122). Isaac Newton on the other hand, also relied on professorship positions in his early life, but when he inherited his stepfather's estate, he was able to live comfortably off of the estate's rent (Westfall, 1995). These scientists lived relatively modestly.

Two centuries later, the industrial revolution was at its peak. Inventors were capable of making more money than ever before by capitalizing on their inventions. Carl Benz, born in 1844, went from living near poverty as a child, to inventing a reliable two-stroke engine. With this engine patented, he went on to found Benz & Cie, sell thousands of cars a year, and begin part of an empire to become Mercedes-Benz (Bellis, 2020) . This was the first time organizations besides governments and religious institutions were capable of gathering large sums of money, and they started investing in research and development as a way of securing long-term prosperity.

At the same time, the American government realized the potential for companies like Benz & Cie to help create the technological infrastructure necessary to better leverage the nation's resources. Unfortunately, large projects are expensive to finish and take a long time to turn a profit, making it hard for corporations to justify the costs. As a result, the government began subsidizing costs for these large-scale projects. As an example, Congress appropriated nearly $1 million (valued in 2020 dollars) to lay out an experimental telegraph line from Washington D.C. to Baltimore, Maryland in 1843 (Morse, 1843). They also aided the railroad corporations with land grants and government bonds. In total, Union Pacific's transcontinental railroad cost over a billion dollars (valued in 2020 dollars) and finished in 1869. Most of that was paid for directly by the railroad companies, and eventually they paid back the government in full for their help (Klein, 2014). With these efforts, the economy and power of the nation was bound to improve and validate the costs for both the corporations and the government.

With the increase in resources in the nation, education also became more accessible. More and more kids attended school and this led to an increase in colleges and research positions. Along with this also came organizations and prizes funded by wealthy individuals with a mission to increase the pursuit and dissemination of knowledge like the Smithsonian. One of the benefactors of this movement was Robert Goddard, "the man who ushered in the space age". In 1917, he was able to fund his rocket research thanks to grants from the Smithsonian and Clark University totaling to $170,000 modern dollars (Lehman, 1962, p.14-16). This was a miniscule sum relative to how much money was spent for rocket research in the decades to follow, but it was enough to create the foundations for the future of space travel.

After seeing the potential for Goddard's technology for military use, the United States Army began sponsoring his work for use in WWI. This government financial intervention was one of many examples of the time where technologies were advanced for the purposes of war. Two decades later in 1941, the United States entered into WWII, and with the war came the largest expenditures for technological advancement that the nation had ever seen. Just with the Manhattan project, which aimed at developing the atomic bomb, over 20 billion dollars were spent (Britannica, 2020). While this amount is a small sum compared to the whole cost of the war, the Manhattan Project became the costliest individual scientific endeavor of American history. Entire communities were built just for this project all across America, and a total of 130,000 people were employed (Atomic Archive) . The power that the Manhattan Project's atomic bomb gave the United States made evident the need for Big Science for national defense. Soon, other incentives for large-scale scientific projects became clearer: economic benefits, quality of life improvements and competition with other countries. With these incentives, the U.S. government began funding more Big Science projects.

Once WWII ended, German scientists and technologies were battled over by the remaining countries — predominantly the U.S. and the Soviet Union. Whoever found the most of the unparalleled German technologies was sure to gain a scientific advantage for the years to come, especially as it related to rocket technology. The United States was able to capture Wernher Von Braun and his team of rocket scientists, who developed the world's first guided ballistic missile, the V-2. Wernher went on to further develop his rocket technology under the support and supervision of the U.S. military. Eventually his team got assimilated to NASA, with Wernher serving as the director of the Marshall Space Flight Center (Brzezinski, 2007, p.1-30).

Immediately following WWII, there was a public sentiment of grandeur. The United States had become a world power, and Americans were unified in their new national and international identity. The gross national product increased by 50 percent over the course of the decade following WWII. Levittowns were built and the middle class expanded. In 1949, Americans were buying 250,000 television sets per month, over ten times more than existed just three years prior. The average family began watching four to five hours of TV a day. Manufacturers converted their military production back to domestic commercial production. After living with rationing policies for several years, families started purchasing luxury goods again ("The Postwar Economy"). Americans were dreaming.

Unfortunately, these peaceful dreams were short-lived. As Martin Luther King Jr. put it, African Americans were "still sadly crippled by the manacles of segregation and the chains of discrimination" (Stanford, 2014). The U.S. got into the Vietnam war, which took 16 years to end and caused the death of over 3 million people, many of whom were civilians. Rising tensions between the U.S. and the Soviet Union over the values of western democracy vs communism instigated fear amongst the American public accentuated by the presence of nuclear weapons on both sides. Americans were afraid.

Many people now look at the 60s as a time of scientific advancement and unification behind the moon missions. But in reality, America was going through tumultuous times (Madrigal, 2012). The space race was fighting with these social and political issues for public attention and support. The arrow was anything but golden, and support for a space program was not widespread and uniform.

Due to the costly nature of NASA though, it was necessary to get a significant portion of the public to support the program.

From its founding in 1958 to the moon landing in 1969, NASA's expenses totaled 294 billion (valued in 2020 dollars), or about $1500 for every American alive at the time of the moon landing. At its peak in 1966, NASA was 4.41% of the federal budget (Rogers, 2010). This was higher than the 2.1% dedicated to education, but smaller than the 40% dedicated to national defense or the 26% dedicated to social security (Bureau of the Budget, 1965). The budget is carefully crafted by the president and then passed onto congress for approval. This process means that the president and congress are held responsible by the public for expenditures of taxpayer money.

As written in a note by the president to congress in the 1966 federal budget,

> *A budget is a plan of action. It defines our goals, charts our courses, and outlines our expectations. It reflects hard decisions and difficult choices. This budget is no exception. It is a budget of priorities. It provides for what we must do, but not for all we would like to do...The Great society must be a bold society. It must not fear to meet new challenges. It must not fail to seize new opportunities (Bureau of the Budget, 1965).*

In a representative democracy such as in the United States, politicians are responsible to the public and can be voted out of office for unwise or unpopular expenditures. So in order for NASA to keep its significant budget throughout the 60s, it needed to have the public's support. This system favors scientific endeavors which are spectacular in nature, as civilians are more likely to be intrinsically motivated to get behind the mission. It is easier to justify billions of dollars in expenses for an attempt to land at the body in the sky we all look at in awe every night, than it is to justify billions of dollars to researching engine modifications to make cars a few percentage points more efficient. The latter has direct applications and could lead to a significant reduction in carbon emissions and gasoline costs, but to most people, it sounds less inspiring and impactful. In order to gather the public support needed to satisfy its budget, NASA had to spend a significant amount of time and effort on media to push its spectacular mission and ensure that America loved astronauts and was excited about exploring space and landing a human on the moon.

With this history in mind, we can take a deeper look into the specifics of NASA's situation throughout the 60s and how it interacted with other forces in action

The public and the media

In 1957, when the Soviet Union launched the first artificial satellite, Sputnik I, man-made objects cruising through space had been true only in science fiction. The moon had been admired for millenia for its mystique and constant presence, and the Soviet Union managed to launch something that shared the same space. If you had tuned into that orbiting thing on your ham radio, you would have heard every three tenths of a second a high pitched blip, progressively getting louder until a seemingly random break made the blips quieter. Every once in a few beats, the blip changed slightly in pitch. "beep beep beep beep beep beep beep..." No words. No broadcaster. Just eerie tones coming from a foreign metal sphere in the heavens. You could have also gone outside at night to spot the thing, looking like a shiny white dot, not unlike a star, streaking across the night sky at five miles a second on its way to dominating the world, making everyone aware of its existence and serving as a symbol of Soviet scientific dominance. If they put Sputnik I into space, it was reasonable to assume that they could put nuclear weapons in space, capable of deploying to any part of the world.

It is this perceived dominance and its implications that ruled the media for the following few years. Sputnik 1 came as a surprise to the American public as it did to the American government. Six months prior to its launch, around 54% of people had not heard of Earth satellites. Six months afterwards, only around 8% hadn't (Dick, 2015, p. 8). This enormous change is because for months after its launch, Sputnik dominated newspapers with headlines like "Sphere crossing U.S 7 times a day", "Western experts Believe Satellite May Last Years", and "Round the World in 96 minutes". This last one was published in the New York Times two days after Sputnik I's launch in early October of 1957 and read:

> *Thus confirmed, the Soviet announcement inevitably was a sobering one for the West, particularly the United States. It tended to confirm the claim by Moscow six weeks ago of the first successful test of an intercontinental ballistic missile, and indicated that the U.S.S.R was — for the moment at least — ahead of the U.S. in the crucial rocket race. (NYT, 1957)*

Sputnik I started the space race, and the Soviet Union was ahead. The United States' first attempt at putting a satellite in space failed miserably, failing to get even 2 meters off of the launch pad. This disaster caused United States opinion to falter across the globe, and Americans started being called "citizens of a second-rate power", only to be made worse when Sputnik II successfully launched a cosmonaut dog to space.

Politicians pushed Sputnik as a symbol of United States failure. How can the most powerful democratic state fall behind the enemy communist one? Adlai Stevenson, a previous democratic presidential candidate, said at the time "Not just our pride, but our security is at stake." (Hoffman, 8:06) As a result of this, Lyndon B Johnson launched a series of hearings to last six weeks starting on November 25 of 1957 to understand the impact of the Soviet achievements and come up with action items for the government to do in the wake of "'consistent underestimation' of Soviet progress, *the Government's 'lack of willingness to take proper risks' and 'the absence of a real unified war plan'" (Morris, 1957).*

Throughout the hearings, the significance of space and the idea of a straggling United States was reinforced in countless newspaper articles, TV broadcasts, and radio shows, eventually portraying a need so important that Johnson and others advocated for massive changes within the government. He pushed for massive education reforms, increased military budget, an advanced timeline for U.S. rocket research, and the restructuring of national priorities to put science on top. The public saw a fundamental change in thought, and similar reforms were pushed for at the smaller scale — in elementary schools, companies, and colleges. Many even took to the Soviet Union for inspiration. At the end of the hearings, Lyndon B Johnson said:

We now have on record the appraisal of leaders in the field of science, respected men of unquestioned competence, whose valuation of what control of outer space means renders irrelevant the bookkeeping concerns of fiscal officers (Wasser, 2005).

With the conclusions arrived at above, congress decided to greenlight the formation of NASA in 1958. Its budget for that year was $797 million (valued in 2020 dollars), and it doubled every year until 1961, after which it still increased until its peak in 1965 of $35 billion for the year (Rogers, 2010).

NASA's Historical Studies in the Societal Impact of Spaceflight outlines several polls that were conducted throughout the space race. The document describes a Gallup poll taken a month after Sputnik I which asked the public why they thought the Soviet's were ahead. It revealed that "only 3.8 percent of respondents rejected the assumption in the question that Russia was ahead." For the rest of the entries, the highest cited reasons as to why Russia was ahead include "President Eisenhower (5.4%)","inter-service rivalry (5.0%)", "inadequate education preparation for science (4.9%)", "neglectfulness (4.8%)", and "the budget (4.7%)" (Dick, 2015, p.8).

This same document mentions another report from three years after NASA's founding:

At the end of May 1961, a Gallup press release reported, 'Kennedy Must Convince Public of Value of Moon Shot Project,' because 58 percent of Americans did not want the estimated $40 billion spent on this, compared with the 33 percent who did (Dick, 2015, 12).

While the barrage of media portraying somber tones led to the public becoming scared and aware of the problems with the Soviets controlling space and its meaning about the inferiority of the United States, the majority did not see eye to eye with Johnson's claim that it was enough to justify the costs, especially as it came to the space program. This is especially true since the public consistently overestimated NASA's budget.

Because of the cost concerns, starting 1961, it was Kennedy's role as president to use the media to persuade the public of the value of the space program. Thankfully for him, he was a man who knew how to use the cameras.

At his inauguration, he exclaimed:

Let every nation know, whether it wishes us well or ill, that we shall pay any price, bear any burden, meet any hardship, support any friend, oppose any foe, in order to assure the survival and the success of liberty... Let both sides seek to invoke the wonders of science instead of its terrors. Together let us explore the stars, conquer the deserts, eradicate disease, tap the ocean depths, and encourage the arts and commerce (Kennedy, 1961)

These words set the precedent to his presidency. Later in the year he set the goal for the Apollo program that the nation should commit to landing on the moon by the end of the decade in a televised speech to congress to be heard by the whole country.

After several successful American rocket launches, Americans started believing that the U.S. was finally ahead of the Soviets when it came to the space race, and so people started caring about Soviet progress less. In a poll taken in October of 1964, 66% of respondents said beating the Russians was "Not too important" (Dick, 2015, p.13). This change in thought marked one of the fundamental shifts in media coverage, as there now needed to be a different motive to support NASA other than beating the Soviets. No longer was the space program being validated just for the purpose of showing the world which system of governance is superior. Now it was to be a mission that the whole country could get behind for the sake of exploration and national pride. This new validation is best shown in Kennedy's famous "we choose to go to the moon" speech in 1962. In it, he looks at human achievements throughout our history, and paints NASA's mission as a legendary adventure to be recalled upon with awe for the rest of human history. He ends with:

Many years ago the great British explorer George Mallory, who was to die on Mount Everest, was asked why did he want to climb it. He said, "Because it is there."

Well, space is there, and we're going to climb it, and the moon and the planets are there, and new hopes for knowledge and peace are there. And, therefore, as we set sail we ask God's blessing on the most hazardous and dangerous and greatest adventure on which man has ever embarked (Kennedy, 1962).

Three years after this speech and two after his assassination in 1965, Gallup conducted another poll on public opinion on NASA's funding. 16% wanted an increase, while 42% wanted it kept the same (Dick, 2015, p. 15). This majority sum of people who in essence supported the cost of the space program shows the public had gained new interest in the space program compared to the numbers advertised in the early stages of NASA's program. Everything started seeming more tangible. Maybe we could reach the moon. That being said, 58% sum is still far from being able to say the vast majority of Americans supported the program.

Another part of NASA's effort to get the public excited about a manned space program was a celebration and glamorization of the astronauts. All of the NASA astronauts became instant celebrities. Their presence was welcomed at events all over the country. Alongside their technical duties, they had media duties. The world wanted to meet them. Michael Collins, one of the astronauts inside of Apollo 11 explains:

NASA is (or at least used to be) flooded with requests for astronauts to make public appearances.. As requests came in, they were routed to NASA headquarters in Washington, where the public-affairs officials (I assume) weighed them on the basis of political clout, persistence, prestige of audience, etc. and then grouped into neat packages. These packages were organized, insofar as possible, within certain limits of geography and time, so that one astronaut could fulfill all of them in one week. Hence the affectionate title of 'week in the barrel' was given to this duty (Collins, 2019, p.93)

This 'week in the barrel' was tough on astronauts, and as such, they were not big fans. They would be asked the same questions over and over again, fanatics would push others to get close to them, and there was little to no rest between appearances. But because of its need for public support and use of taxes, they had to do it.

This same theme was present during missions. Astronauts were trained in the handling of TV cameras. Launches were televised. Newspapers announced major achievements accomplished during missions. Radio listeners were able to tune in to hear the astronauts speak. And after the astronauts came back, news reporters would ask questions during post-mission debriefs. During these missions, the necessity to have media moments made the crew more upset at times than on the ground. Michael Collins describes the following during his Gemini 10 mission:

> *the reporters at the news center in Houston are not going to be satisfied with a vague promise of scientific results to be published at some future date, they want hard news, they want quotes, and they want them right now. The American public has a *RIGHT TO KNOW!* Never mind that we are busier than two one-legged men in a kicking contest (Collins. 2019, p.218)*

Several key events had an especially large impact on public opinion.

John Glenn's three orbits around the Earth during the Mercury-Atlas 6 mission made him an instant hero. He is commonly described as being great with the media, and the nation loved him. According to a Gallup survey in 1963, "89 percent of Americans were able to name Glenn's occupation... In the same poll, only 84 percent of Americans knew Richard Nixon's main occupation. (Nixon had been the Republican nominee for president just three years earlier)" (Henry, 2016).

During Gemini 4, pictures of America's first spacewalk spread all over the world. Ed White had his arms extended, while carrying a self-propulsion gun to propel him in any direction in the absence of gravity, just floating with the Earth and a slice of space in the background. This wasn't the first time a picture of the Earth had been released, but seeing a human in the picture floating from nothing but a tether added some magic to it. One human in the foreground, and billions of others in the background. These pictures of Earth were particularly enjoyed by the public.

After the disaster in 1967, where Gus Grissom, Ed White, and Roger Chaffee died inside of the Apollo 1 cabin in a tragic fire during a launch rehearsal, many people who had supported the program before, questioned again whether the lives and money were worth the effort. A few weeks after the incident, only 33% favored the moon landing effort (Dick, 2015, p.13). For the following year, no crewed missions flew.

Apollo 8, the first mission after the Apollo 1 disaster, recouped some of the loss in public support. It was the first crewed mission to orbit the moon, or as Michael Collins describes, the "first time in history, man was going to propel himself past escape velocity, breaking the clutch of our earth's gravitational field and coasting into outer space as he had never done before" (p. 305). The mission's outcome is estimated to have been heard of by one half of the world. "There were more newspaper reporters at the Cape than for any flight since John Glenn's". 6 months before Apollo 11, the 33% support for the space program went up to 39% (Dick, 2015, p.16).

Apollo 11 was poised to be a worldwide media sensation. With its mission to land humans on the moon and complete Kennedy's goal, it drew in crowds never seen before. 600 million people watched the TV broadcast. That was one in six people in the entire world simultaneously all paying attention to the same story. It was the largest audience that had gathered for a single TV broadcast, ever. The percentage of people who said Apollo was worth the cost now was 54 percent (Launius, 2013, p.168). While this larger support is too late to garner more resources for the moon landing mission, it was still good for the purposes of justifying NASA as an organization, and potentially enable future missions.

To this day, Neil Armstrong's famous words are ingrained in the minds of just about every American: "It's one small step for man. And a giant leap for Mankind".

Not long after Neil and Buzz planted the United States flag on the moon, they got on a call with President Nixon while they were still on television and being watched by hundreds of millions of people. Nixon remarked:

> *Hello, Neil and Buzz. I'm talking to you by telephone from the Oval Room at the White House. And this certainly has to be the most historic telephone call ever made. I just can't tell you how proud we all are of what you've done. For every American, this has to be the proudest day of our lives. And for people all over the world, I am sure they too join with Americans in recognizing what an immense feat this is. Because of what you have done, the heavens have become a part of man's world. And as you talk to us from the Sea of Tranquility, it inspires us to redouble our efforts to bring peace and tranquility to Earth. For one priceless moment in the whole history of man, all the people on this Earth are truly one: one in their pride in what you have done, and one in our prayers that you will return safely to Earth (History.com Editors, 1969).*

After the Eagle landed on the moon, the world went crazy. Two years later, a poll showed 81% of Americans thought "Nothing can equal seeing the astronauts land and walk on the moon as it happened live on TV" (Dick, 2015, p.33). Again, newspapers were filled with exciting headlines. Notable headlines from The Chicago Tribune included "Pope Hails Success of Apollo 11, Offers Blessing for its Crewmen", "World Pauses, Peers, Praises Lunar Conquest". The Washington Post had "Apollo Lesson: Where There's a Will". The Economist, a European newspaper, said "And to the planets, sooner rather than later, man is now certain to go. If he went tomorrow, it would be American man, with Soviet man at his heels and the rest of the industrialized world nowhere" (Economist, 1969). Another quote from the Wall Street journal is also particularly meaningful. It reads:

> *Therein may lie the human meaning of the mission that ended with its Pacific splashdown yesterday. That man can walk on the moon does not prove he can do everything, but it does prove he can still do something. In that there is a measure of hope for a doubting age. (WSJ, 1969)*

After the Apollo 11 crew finished their quarantine to insure against the unlikely possibility they carried pathogens from the moon, they went on a tour of the world using the vice-president's star-spangled airplane, stopping at a total of 24 countries in 38 days. They were received by massive crowds and world leaders like the Queen of England, the Shah of Iran, the Emperor of Japan, and the Pope. Throughout the tour, it is estimated that over 100 million people came to see them (Kelli, 2019). As a staff member who went with them said, "There were crowds everywhere… there was a lot of interest in the astronauts." (Barnes, 1999) They were global sensations.

But all of this was short-lived. The question in the minds of Americans was: "What's next?"

Kennedy had defined the goal for NASA so well: to land man on the moon by the end of the decade. It inspired many and got contractors and engineers to work effectively to fulfill the deadline. However, he may have defined it too well. Many saw the goal achieved, and the lack of media supporting further goals throughout the 60s meant that there was not as much public support for any large challenge after the moon landing. A Gallup poll taken in 1969 showed only a 39 percent support for a Mars landing mission, 31.5 percent support for a permanent American space station, 38 percent favored an international space station, and 34 percent support for putting an exploration station on the moon (Dick, 2015, p.16).

At the same time, the United States became more involved in the Vietnam War. Lyndon B. Johnson found himself in a conundrum. Large sums of money were being spent on both NASA and the Vietnam War, and one effort had to see decreases. Johnson chose the former's budget to decrease in 1967 after negotiating a deal with the Soviets, where neither could put nuclear weapons in space or claim ownership of the moon (Wasser, 2005).

Johnson started the decline of funding for the space program, but Nixon, after he took the presidency in 1969, sealed the fate of NASA for many decades. With respect to the space program, Nixon said in 1970:

> *We must think of [space activities] as part of a continuing process… and not as a series of separate leaps, each requiring a massive concentration of energy. Space expenditures must take their proper place within a rigorous system of national priorities. … What we do in space from here on in must become a normal and regular part of our national life and must therefore be planned in conjunction with all of the other undertakings which are important to us. (Callahan, 2014)*

Along with thinking of the space program as just like every other national program, and "not a privileged activity", Nixon also set a stop to programs beyond low earth orbit, effectively eliminating any hopes for further moon or mars programs. In December 1972, as Apollo 17 was returning to Earth, Nixon issued a statement saying, "This may be the last time in this century that men will walk on the Moon" (Callahan, 2014).

Space Media Today

We are now in 2020, and no one has set foot on the moon since the Apollo missions. NASA's budget as a proportion to the federal budget has consistently been decreasing, now at 0.48 percent ($22.5 2020 dollars). According to a poll by C-Span and Ipsos in 2019, around the time of the 50th anniversary of Apollo 11 in July, when asked about what the two top priorities of NASA should be, only 8 percent included a manned mission to the moon, and 18 percent said a manned mission to Mars (C-SPAN/Ipsos, 2019).

At the same time, 78 percent of respondents said they have a favorable view of NASA, compared to 7 percent which said they saw it unfavorably. When asked about NASA's 0.5 percent slice of the federal budget, 41 percent saw it as too little, 49 percent as about the right amount, and only 8 percent saw it as too much. People now are fascinated by the epic stories of the Apollo missions, and support NASA as an organization, but there is little public love for manned missions to other celestial bodies.

In 2004, President Bush announced the Constellation program, aimed at returning to the moon by 2020, and extending human presence across the solar system and beyond. Just six years afterwards, the program was cancelled by Obama's administration, citing that it had unreachable goals unless NASA's budget was significantly increased (Harland). Again, hopes to reach the moon were thwarted for some time. In December of 2017, President Trump signed Space Policy Directive 1, which had goals to use private company partners to reach the moon again, establish a base, and use it to develop capabilities to reach other planets. In 2019, the program was labeled "Artemis", and the timeline was shortened, with a planned moon landing in 2024. Unlike Apollo though, few people actually know about Artemis. In the same C-SPAN/Ipsos poll above, only 10 percent of respondents said they were familiar with the Artemis missions. For comparison, 23 percent of people felt familiar with the Space Force. This lack of public knowledge, and thus interest, is one main reason why NASA's budget has not been increased.

By using Google Trends, which looks at the popularity of searches on the platform, we see two peaks in popularity for the search term "Artemis" in the last five years. When the name Artemis was announced in March of 2019, the popularity was just 2.3 points above the baseline. The first peak, with a popularity of 77.3 points above the baseline, was when the 263rd box office grossing movie "Hotel Artemis" was released. The second peak, with the peak popularity, was when the movie "Artemis Fowl" was released. If you subtract the baseline, about 30x more people were looking into a movie which did not even pass its budget in box office revenue, than were looking into the moon landing program when its name was announced or the timeline decided.

There is a national goal to reach the moon by 2024, and the public is not even aware. Why is this?

Firstly, there is no equivalent to Kennedy's "We choose to go to the moon" speech. Kennedy's by-the-end-of-the-decade goal was heard throughout the nation and put on all media channels, but the current goal to get to the moon by 2024, is heard by no one. The current and previous presidents have declared their support of NASA and manned missions, but have not labeled it as one of their major areas of political concerns. They have managed to for the last ten years stop the decrease of NASA's share of the federal budget, but have not yet managed to convince the public to push congress to give NASA an additional $20-30 billion over the next few years estimated to be necessary in order for the modern moon landing program to be successful. This rather large sum of money is contesting support with other current political movements, and has not been taken as a priority by recent politicians. It would take a president with a true passion for science and space exploration to motivate the public to push Congress to give more money to NASA.

Secondly, there is no external force like Sputnik I to push a president to take the NASA agenda further. One could try to argue that the current battle between China and the United States for tech is similar, but the current public sentiment of China is nowhere near as close as was that against the Soviet Union during the Cold War. Back then, kids were taught how to attempt to survive a nuclear attack by the Soviets. Now, kids are taught that using a Chinese social media application is bad. The current Coronavirus situation could be used as a platform to advocate for increased science education in the name of stopping a future pandemic, but instead, it is being used as a political missile, and the science is largely ignored. Interestingly, Russia recently registered the first vaccine against COVID-19, and named it Sputnik V in an attempt to use it as propaganda, alluding their early vaccine to their early advantage in the space race with the Sputnik I satellite. This too has been futile, as it has already been discovered to be potentially incredibly dangerous as a product of careless rushing by the Russian government. There has been no wake-up call produced by an external agent.

Lastly, NASA's marketing itself has failed to garner public support for larger missions. For example, there is a distinct lack of media relating to NASA's ambitious goals on popular media outlets. In the 60s, it was common to see front page headlines about the space program, but now, there are rarely any. While most people now are familiar with some of the famous astronauts from the 60s, they cannot name any modern astronauts. NASA's videos on YouTube also struggle to reach more than a few hundred thousand views.

While these large forces for change are not in action, there is a growing smaller force that shows a glimmer of hope.

Over the last few years, SpaceX, the private rocket company, has risen dramatically in adoration from the public. There are a few other private space companies that are making the media rounds like Blue Origin, Virgin Galactic, and Rocket Lab, but SpaceX is by far the one with the most public attention and furthest ahead in terms of rocket capabilities, so let's take a look at them. SpaceX's rocket launches, which arguably go the exact same every time, consistently gather millions of viewers on YouTube. Their first test flight of the Falcon Heavy rocket, has been seen 28 million times. NASA's current three most popular videos(18M, 17M, and 14M views) are streams from SpaceX's crew dragon mission to the ISS. SpaceX has achieved this media success by aligning their content more with contemporary culture. When testing Falcon Heavy, instead of launching a boring concrete payload, SpaceX launched a Tesla Roadster with an astronaut costume mannequin at the driver's seat. And when promoting the mission, they acquired the rights to play David Bowie's Life on Mars song and used it in their animation to make their video more exciting. SpaceX's marketing is fun and successfully motivates a significant section of the public. These private companies are one hope America has for an exciting space future. Largely though, these companies also rely on funding from the U.S. government and NASA in the form of contracts to launch federal satellites and astronauts to the International Space Station. So in order for private space companies to succeed, NASA also needs to succeed.

In the late 50s and early 60s, it took three main things to get the public support required to fund the space missions: a foreign satellite going up, thus scaring American citizens and shaming the nation on the world stage, politicians like Lyndon B. Johnson and John F. Kennedy who pushed for manned space missions, thus labeling NASA as a top national priority, and a solid marketing strategy on the part of NASA. Now, there is no strong advocacy at the presidential level, no race with a foreign nation to scare the US into space research, and NASA's marketing has failed to use the peoples' ingrained interest in space to motivate them towards wanting challenging space exploration objectives. All this leads to no push by the public, and thus no push by the government for an increased space agenda.

Average modern American citizens love to look at the stars, think about what's out there, and reminisce about the storied past of the Apollo program, but they are not aware of current space developments, and are not pushed to support manned American space exploration.

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Developing a Sensory Substitution System for Vibrotactile Feedback in Patients with Peripheral Neuropathy

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Sensory loss is common following a neurological injury, with a prevalence of 50% of stroke survivors showing different degree of sensory impairment. To a great extent, stroke survivors with significant sensory deficit show poor motor recovery. Here, we present the proof-of-principle of a novel sensory substitution system that provides vibrotactile feedback during gait for patients who have lost kinesthetic and haptic perception on their lower limbs. Pressure or inertial measurement sensors were mounted on a custom-made open type of footwear that resembles sandals, secured to the stroke participant's shoes. Haptic and inertial sensor data is transmitted via a local wireless system to a central processing unit mounted on the participant's belt where the phases of gait cycle are identified in real-time and used to command coin cell-sized motors, mounted on the upper part of the leg, to vibrate. We tested the feasibility of system as an assistive technology and in the future we will examine its potential as a rehabilitation tool.

1. Introduction

A lack of tactile information and proprioception (awareness of the position and movement of the body) results in an abnormal gait cycle, as in the case of stroke patients. Depending on the severity of the stroke, approximately half of stroke survivors reported impaired tactile sensations (Connell, 2008). Up to 50% of patients with diabetes develop diabetes peripheral neuropathy, which causes a disruption in the sensorimotor system and often leads to abnormalities in gait (Alam, 2017). In many cases, these patients are confined to walkers, wheelchairs, or other forms of assisted walking devices for the rest of their lives.

Loss of tactile sensation and proprioception requires compensatory techniques that typically slow down human gait and limit ambulation. For example, many patients may use visual information to compensate for the lack of haptic feedback in the foot; however, this presents many challenges including depth perception and the need to constantly look at one's feet in order to walk. The human body has four major types of tactile receptors (Boundless Biology, 2020), each of which responds maximally to certain sensation: light touch, vibration, skin stretch, and deep pressure. Because of this diversity, patients with impaired gait due either to neuropathy or internal brain damage often retain sensation in some classes of tactile sensors, while losing others. We focused on the implementation of a device for patients who retain vibration sensitivity in their upper part of their lower limbs, regardless of their sensation (or lack thereof) of touch, pressure, and skin stretch more distally on their body.

In this paper, we present the development of a sensory substitution system that provides vibrotactile feedback dependent on the wearer's current gait cycle phase. The system consists of two shoe slips, each containing pressure sensors and an inertial measurement unit (IMU), that communicate wirelessly with a controller (the master node) which determines gait cycle events depending on the received data and triggers vibrotactile

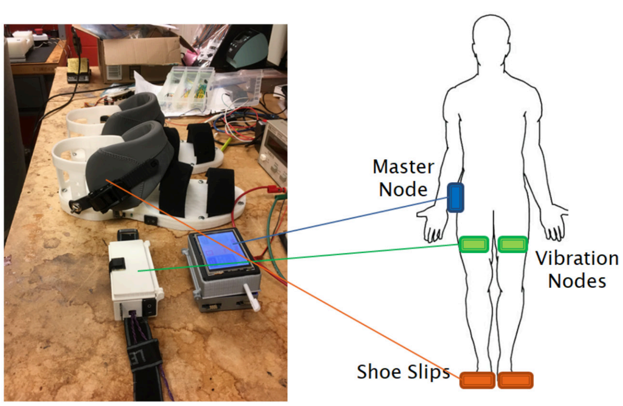

Figure 1: Sensory substitution system module placement on body

motors worn around the user's upper thighs (Figure 1). For this proof-of-concept and feasibility study, we employed two very simple algorithms for classifying an impaired gait cycle: one using pressure sensor data, and the other using gyroscopic and accelerometer data collected from an IMU. This is because while pressure sensors might afford a more reliable identification, their lack of long-term robustness make them less desirable than an IMU. More sophisticated algorithms with far superior classification scores can be found elsewhere (Pérez-Ibarra, 2018). We assumed that the first algorithm employing the foot pressure sensors determined accurately the "ground truth" in gait cycle classification, and hence this "ground truth" was used to evaluate the second IMU-based algorithm.

2. Overview of Sensory Substitution System

The system consists of three modules (Figure 2):

- Shoe slips with four Interlink 402 force-sensitive resistors (Interlink Electronics; Westlake Village, CA) placed under high pressure areas of foot and a BNO080 inertial measurement unit (CEVA Hillcrest Labs, Mountain View, CA) with 9 degrees of freedom and a 16-bit data output resolution.
- Vibration belts worn around the upper thigh embedded with two 10mm diameter motors with an eccentrically shaped rotating mass. One is located on the front of the thigh, while the other is located on the opposite side, halfway around the circumference of the thigh. A microcontroller generates a PWM waveform with an adjustable duty cycle that controls the amplitude of the vibrations, producing varying intensities against the patient's legs at a fixed frequency (around 12,000 Hz). The vibrations are strong enough to be felt through a thick layer of clothing.
- A master controller that processes the data to classify the current phase of the gait cycle and trigger the vibration motors accordingly.

The design of the sensing apparatus worn on the patients' feet was developed based on the unique needs of sensory-deficient patients. We gathered the critical parameters we believe are necessary for a sensory substitution device to be useful:

- Robustness, i.e., protections against sudden impacts and shocks.
- High level of accuracy and precision in gait detection.
- Low weight
- Ergonomic design, so it can be worn comfortably for extended periods of time.
- Longevity in expected use-case scenarios.

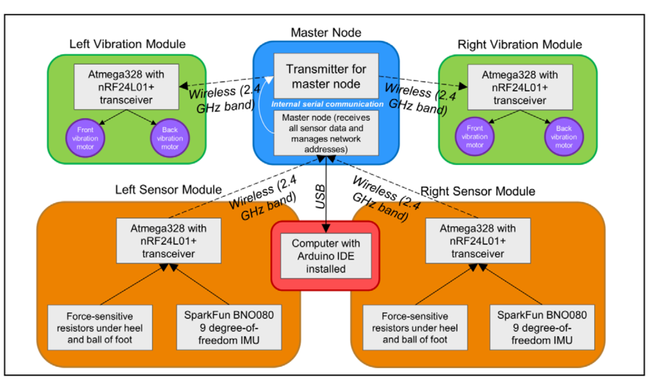

Figure 2: Block diagram of sensory substitution system (Bolli, 2018)

Three initial designs were tested: a box mounted around the ankle with an IMU to record acceleration and angular velocity (design 1), an external shoe slip worn underneath the shoe containing an IMU and four pressure sensors (design 2), and a variation of design 2 where the microcontroller and supporting circuitry were strapped over the patient's shoe for an extremely thin (1.6 mm) shoe slip (design 3). The designs were evaluated using a weighted rating system shown in table 1, based on metrics from the list of target specifications.

Each category's weight is listed in parentheses, with a maximum weight of 5. Designs were ranked on a scale of 1-5.	Robustness (3)	Accuracy (5)	Weight (1)	Ergonomics (3)	Longevity (5)	**Total score**
Design 1 (ankle-mounted box)	5	1	4	3	5	**58**
Design 2 (thick shoe slip)	4	5	2	3	4	**68**
Design 3 (thin shoe slip with external microcontroller)	3	5	2	4	3	**63**

Table 1: Design Selection Criteria

The second design was chosen over the first design due to the differential benefit of the presence of the pressure sensors, whose readings complement those of the IMU and reduce the number of

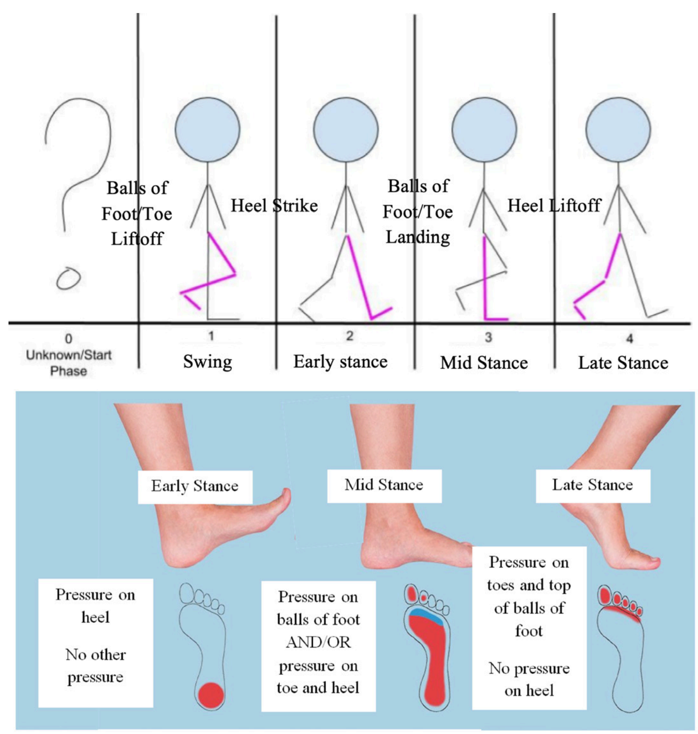

Figure 3: Simplified phases of gait cycle with corresponding pressure areas. Adapted from (Poole, 2019).

false triggers. Furthermore, the second design proved to be more robust than the third one due to the lack of any exposed wires.

To determine the location of the pressure sensors, we used a simplified model of gait cycle consisting of four phases: early stance, mid stance, late stance, and swing. Unique motor events were chosen to correspond to a change in phase; for example, a heel strike indicated a change in phase from swing to early stance

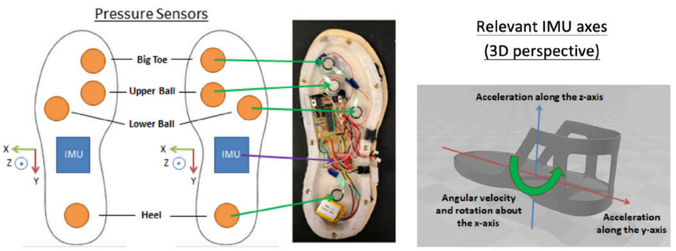

Figure 4: Location of sensors in the MIT Pedes shoe slips (left) and relevant IMU data used in classifying gait (right).

(Figure 3). Each of these motor events precipitated a different distribution of pressure across the foot, as shown.

The locations of the pressure sensors correspond to the areas on the foot where pressure would be expected during each event: under the heel, under the balls of the feet, and under the toe (Figure 4). For the shoe slip to fit as many patients as possible without repositioning the sensors, the sensor placement was validated on patients with shoes sizes of 7 to 13 (men's shoe sizes, USA standards), which encompasses the vast majority of adults, both male and female.

The system was optimized for simplicity and patient customization. Though all enclosures were designed to fit the majority of adults, their dimensions can easily be adjusted in CAD software to fit patients whose dimensions differ from the selected range. The shapes of the enclosures were designed to ergonomically complement the parts of the body. They fit over and were fabricated using rigid PLA (vibration modules and master node) or semi-flexible PCTPE (shoe slips) and hold the electronics and batteries in a small, discrete area.

The total cost of the system is roughly \$175, including all of the plastic filament, electronic components, motors, and circuit boards. Atmega328 microcontrollers were used as for each node due to their low cost, versatility, and simplicity to program using the Arduino IDE. Two rechargeable 3.7V lithium polymer batteries provide power to each node, with an estimated runtime of 8.3 hours (Bolli, 2018). Pressure sensor and IMU data is sampled at a rate of 20 Hz, because the maximum angular frequency of the ankle is 15 Hz (Antonsson, 1985) and patients typically move their ankle well below the maximum frequency.

All modules communicate wirelessly using a low-power nRF24L01+ RF transceiver (Nordic Semi-conductor; Oslo, Norway) set up in a mesh configuration with reconfigurable dynamic node addresses. This distributed network model allows nodes to direct network traffic through other nodes for efficient and robust communication. Routing and error-checking are managed with the RF24, RF24Mesh, and RF24Network Arduino libraries written by TMRh20. The baud rate is 1 Mbps, more than is necessary for sensor data transfer. To facilitate data collection for gait cycle analysis, the master node was equipped with a USB port for transferring sensor data to a computer. This data can be read from the Arduino serial monitor and stored in a spreadsheet for further analysis.

3. Methods

A gait classifying algorithm was developed using both pressure sensor and IMU data as part of the feasibility test of the sensory substitution system. Data was collected from 7 healthy and 2 impaired gait cycle patients (1 stroke, and 1 spina bifida) on a treadmill test (Figure 5). In all cases, the treadmill was not tilted relative to the ground. Subjects were instructed to begin walking at 2.4 km/hr (healthy) and 1.0 km/hr (impaired gait), with the speed increasing in four increments of 0.4 km/hr to a maximum of 4.0 km/hr (healthy) and 2.6 km/hr (impaired), or to the maximum comfortable walking speed. The shoe slips of the sensory substitution system were attached to the patients before the tests. After the patient reached the initial speed, we recorded pressure, IMU, and video of the gait for 60 seconds. Recording was paused and the speed was increased to the next increment.

The video was synchronized with the recorded data by comparing the video frames to the timestamps (circled in red) on the console output on the computer.

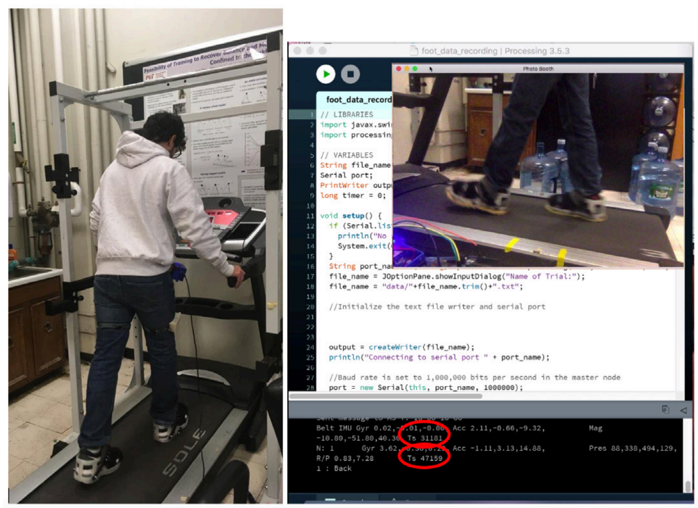

Figure 5: Treadmill tests (left), console output (bottom right), and gait video (top right).

Gait Phase Classification using Pressure Data

The hardware uses a 10 bit analog-to-digital converter (ADC) to map the analog signal of the pressure sensors. Previous testing had shown that the resistance of the pressure sensors approximates a power curve with a negative exponent (Bolli, 2018), meaning that the pressure sensors are very sensitive to small changes in force, but as more force is applied, they become saturated and the resistance changes very little.

Gait cycle was extracted from pressure sensor data using a thresholding algorithm. The algorithm classifies the gait cycle data into one of four phases: early stance, mid stance, late stance, and swing, based on the detection of specific gait events that cause a change in gait phase (Figure 6). A three-point moving average filter was used to attenuate minor fluctuations in data. Having multiple events that can trigger a change in gait cycle phase leads to robustness in classification even if a pressure sensor is malfunctioning.

Four main pressure events were used to determine changes in gait phase: heel strike, balls of foot and/or toe landing, heel

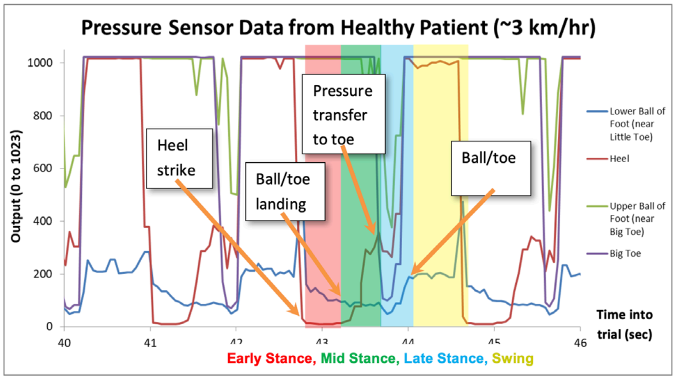

Figure 6: Phase classification of a single complete step using pressure sensor data.

liftoff, and balls of foot/toe liftoff. More force applied results in a lower reading from the analog-to-digital converter. The shaded rectangles correspond to the four phases of the gait cycle the algorithms identify.

The gait cycle video was analyzed manually and segmented frame-by-frame to establish a reliable baseline gait phase classification to compare to future algorithms. Due to the time and labor involved, this process was done sparingly on subsets of the data set solely to confirm that the adaptive pressure algorithm was accurate enough to be used as a "ground truth." Using this baseline, we developed the pressure algorithm to be accurate enough that segmentation of the video was no longer needed to obtain a "ground truth."

Gait Phase Classification using IMU Data

Accelerometers and gyroscopic sensors, often packaged as an inertial measurement unit (IMU), are being increasingly used for gait cycle analysis due to their small size, low power requirements, durability, and low cost (Pérez-Ibarra, 2018). An IMU containing an accelerometer and gyroscope was mounted in the shoe slips underneath the arch of the foot, as shown in Figure 4. The pressure

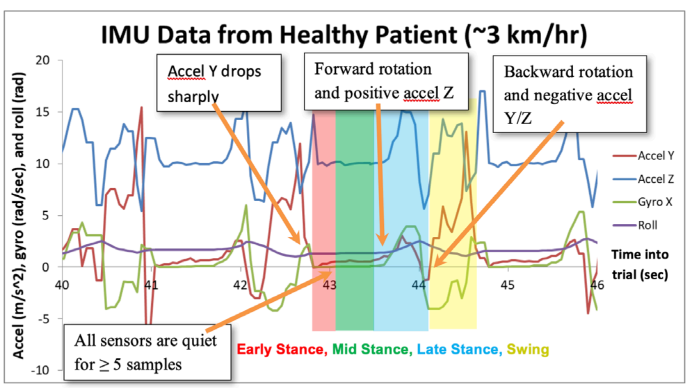

Figure 7: The corresponding IMU signals that accompany changes in gait.

sensors had been found to provide reliable gait classification (table 2), but had to be replaced as they failed after repeated use.

We developed a simple algorithm to classify gait phase from the IMU data, using the classification of the pressure thresholding algorithm as the ground truth. As with the pressure algorithm, the IMU algorithm segments the gait cycle into four phases: early stance, mid stance, late stance, and swing. Events that corresponded to a change in gait phase were identified and used as the basis of the algorithm (Figure 7). Only the y-axis and z-axis accelerometer data, angular rotation around the x-axis from the gyroscope, and roll were analyzed. The other data was mostly involves lateral movements and tilts not integral to the gait cycle (see Figure 4).

Algorithm Results

Two metrics were used to evaluate the usefulness of the simple algorithms: point-by-point comparison and F1 score. In the former, the evaluated algorithm's gait phase classification was compared pointwise with the ground truth for all data points in which the ground truth had a phase classification. The F1 score is a measure

$$F_1 = \frac{2(precision)(recall)}{precision+recall} = \frac{2(TP)}{2(TP)+FN+FP}$$

of accuracy in binary classification. Unlike the point-by-point metric, in which gait phases are compared, the F1 score analyzes gait events that trigger a change in gait phase. Mathematically, it is defined as the harmonic mean of the precision and recall:

where TP = true positives, FN = false negatives, and FP = false positives. An F1 score of 1 is best (all – and only – "ground truth" gait events are retrieved by the algorithm), while a score of 0 is worst (no "ground truth" gait events are retrieved by the algorithm). Failing to classify or falsely reporting gait events also

	Pressure Sensor vs. Video Classification (n=1 healthy participant)		**IMU vs. Pressure Sensor Classification (n=7 healthy participant)**	
	Average point-by-point gait classification similarity	Average F_1 score (±200 ms window)	Average point-by-point gait classification similarity	Average F_1 score (±200 ms window)
2.4 km/hr	0.9122	0.9724	0.8584	0.8792
2.8 km/hr	0.9260	0.9682	0.8882	0.9025
3.2 km/hr	0.9262	0.9704	0.8892	0.9283
3.6 km/hr	0.9637	0.9589	0.9254	0.9712
4.0 km/hr	0.9572	0.9705	0.9632	0.9170
Average	**0.9370**	**0.9681**	**0.9049**	**0.9196**

Table 1: Performance of Pressure Sensor and IMU Gait Classification in Patients with Normal Gait Cycle

decreases the F1 score. A window of ± 200 ms was used for the F1 score to account for the different response times of the pressure sensors and the IMU. Participants with impaired gait cannot walk as fast as healthy ones (tables 2a and 2b).

The central processing node triggers the vibration motors to provide haptic feedback for the user, in the hope that this extra sensory information could facilitate a smoother gait less dependent on visual information. Our F1 scores for persons with impaired gait might render dangerous situation by misclassification, but many algorithms have been developed that can reliably detect gait cycle in impaired patients using only an IMU with an F1 score of >0.95 (Pérez-Ibarra, 2019), so we are confident such algorithms could be used on our system for reliable gait identification and sensory substitution.

4. Conclusion

Our sensory substitution system presents a novel, low-cost opportunity that may help persons with impaired gait improve their mobility. All parts of the system can be manufactured using rapid prototyping equipment and off-the-shelf components for less than $350. The lightweight and modular nature of the system, combined with its durable construction and use of rechargeable

Stroke Participant	IMU vs. Pressure Sensor	
	Average point-by-point gait classification similarity	Average F_1 score (±200 ms window)
1 km/hr	0.6471	0.6310
1.4 km/hr	0.7410	0.7396
1.8 km/hr	0.7741	0.7800
2.2 km/hr	0.8257	0.8160
2.6 km/hr	0.8700	0.8561
Average	**0.7716**	**0.7645**

Spina Bifida Participant	Pressure vs. Video Classification		IMU vs. Pressure Classification	
	Average point-by-point gait classification similarity	Average F_1 score (±200 ms window)	Average point-by-point similarity	Average F_1 score (±200 ms window)
1 km/hr	0.9161	0.9671	0.7521	0.8523
1.7 km/hr	0.9349	0.9538	0.6846	0.8587
2.3 km/hr	0.9533	0.9367	0.5557	0.6063
Average	**0.9348**	**0.9525**	**0.6641**	**0.7724**

Tables 2a and 2b: Performance of Pressure Sensor and IMU Gait Classification in Patients with Impaired Gait

batteries, allow the participants to take it virtually anywhere. We plan to assess the device's usefulness as an assistive technology for human rehabilitation and gait augmentation.

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City Actions

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In this paper, I present a notion of rationality for cities that is thicker (i.e. normatively more demanding) than a means-end notion of rationality. In this view, a city acts rationally when it efficiently pursues a desire it ought to have, whereas in a means-end view (as presented in Easwaran, 2019), a city acts rationally when it efficiently pursues a desire it has, regardless of whether in ought to have that desire (Easwaran, 2019). Additionally, my motivation for believing cities to be rational units comes largely from the way we talk about them, in addition to other distinctive factors of cities. I am interested in how linguistic usage of "cities" interacts with a conception of rationality for cities.

There is potential for multiple notions of rationality for cities to coexist and serve different purposes; here, I compare and contrast this thicker notion of rationality for cities from Kenny Easwaran's means-end notion of rationality for cities, concluding with a discussion of whether and how cities might benefit from thinking about rationality.

Introduction

Kenny Easwaran argues that a city acts rationally when it efficiently pursues its desires (Easwaran, 2019). Here, I will argue that a city acts rationally when it efficiently pursues desires it ought to have. I will begin with a discussion of why I think cities are evaluable for rationality. Since there are numerous cases in which we refer to cities acting rationally or irrationally, denying a city's ability to be evaluated for rationality would be revisionary. Indeed, the ways in which we talk about cities provide key insights for rational evaluation.

I will also discuss the primary divergence of my view from Easwaran's. Finally, I will conclude with a discussion of whether cities ought to be concerned with rationality.

Easwaran argues for a notion of rationality for cities "to evaluate how well some individual or community is doing at living up to its own goals." He also focuses on specific actions, not cities as a whole (Easwaran, sec. 6).

He thinks of a city as "the group of people whose fate is tied up with each other as a result of their geography" (Easwaran, sec. 4.1). It is this sense of intertwined existence that he cites constitutes cities' being evaluable for rationality. Motivated by observable differences in cities' infrastructure and social customs, Easwaran investigates the literal ability of cities to do things that are rational or irrational. His notion does not evaluate an agent's desires; it merely evaluates whether an agent is meeting its desires (Easwaran, sec. 3.1)

Easwaran claims that because certain desires are shared among inhabitants of a city, and inhabitants of a city live intertwined lives, these inhabitants act collectively in response to their shared desires. People do not necessarily have these shared desires for the same reasons, and they do not necessarily have these desires for the same subjects. Easwaran submits that even if his concept of rationality for cities fails to meet standards for group rationality, his "'pseudo-rationality'" for cities is still relevant for design and policy (Easwaran, sec. 3.2).

Like Easwaran, I feel that it is useful to apply rationality to cities even if cities do not in fact meet the requirements for rational units. I am also investigating a notion of rationality that can help reveal whether cities are meeting their goals. However, Easwaran places less emphasis on what the goals of the city ought to be.

Why Rationality for Cities?

In the Easwarian view, rationality for cities has a lot to do with the geography of cities and the influence residents are able to have on one another's lives. He argues that the sense of closeness found in the physicality of the city makes a certain kind of collective action possible, whether it be true collective action or approximate collective action.

I agree that there is something significant about the structure of cities, but I think there is also empirical evidence that cities are evaluable for rationality.

I assume that if it is rational to say that a city acts rationally or irrationally, then a city is evaluable for rationality. Those who do not agree with this assumption will read me as discussing an approximate collective action (a concession also made by Easwaran when suggesting his view could be one of "'pseudo-rationality'" (Easwaran, sec. 3.2)).

My motivation for thinking that it is rational to say that a city acts rationally or irrationally is quite simple. It is quite common to say that a city has acted rationally or irrationally, and it seems to be pretty useful. For example, sentences like "That policy was irrational for New York," or "It is rational for New York to social distance" sound natural. Replacing "New York" with "New Yorkers" changes the meaning of the sentences; New Yorkers could social distance anywhere, but New York can only social distance in New York. The rationality of the action does not have to do only with the actors involved, but with the city itself.

If I want to communicate that I think a certain policy or ruling worked against my city's interests, then the most effective way to communicate that seems to be declaring the action irrational. Since the rationality of the action is not tied to a specific individual or group of individuals but to the city itself, it makes sense that the action was irrational for the city. When a city is the subject of a sentence, the sentence's meaning contains some notion of a complex network of people and systems performing the action. The people of the city do the doing, but they do it in the context of being part of the city in some role or roles.

The Easwarian approach emphasizes the intertwining of lives that is prominent in cities. Beyond local government, Easwaran emphasizes the importance of physicality in collective behaviors of city inhabitants (and thus, city action). He is not focused on city limits, but geographical areas. He focuses on rationality at the city level because of a unique sense of self-sufficiency in cities. (Easwaran, sec. 4.1)

My method for arriving at rationality for cities does not deal with any kind of standards for group action or first principles related to group action. Rather, it takes an empirical approach, drawing from how people tend to talk about cities. Since we talk about cities as rational units, it seems that doing so is useful.

A primary implication of this difference is that my view leaves more space for units other than cities to also be considered for rationality. My argument applies to many entities, including neighborhoods and countries.

The same could be said about the Easwarian argument. Lots of other groups live an intertwined existence. In a battle, for example, the people involved on opposite sides are constantly interacting and influencing one another. However, they do not constitute a rational unit. Each person does not have a role in a larger group that is those people. They are multiple groups that are interacting, but they are not a group.

It seems that either approach, when applied to groups other than cities, has the potential to declare something a rational unit when it is not. However, it does not seem that either approach will declare something a rational unit that it is completely useless to consider as such. Even if this is the case, since both my justification and the Easwarian justification for rationality declare cities to be evaluable for rationality, there seems to be something useful in doing so. Thus, we can turn to discussion of what it is for a city to be rational and how a thicker notion of rationality for cities can exist alongside the Easwarian view.

Desires Cities Ought to Have

Kieran Setiya argues that "general efficiency" cannot be a virtue (Setiya, 2005). If we assume that rationality is not a bad quality to have (Setiya, p. 334), then we conclude that "Practical rationality must be at least compatible with ethical virtue, as general efficiency is not" (Setiya, p. 337). Setiya argues for "specific efficiency," or the effective pursuit of some desires, but not all of them. That way, he argues, virtuous actors need not even consider pursuing malicious desires in order to act rationally: "In the generally efficient person, the deliberative weight of nasty desires can only be outweighed, never silenced, and the silencing of such desires is part of ethical virtue" (Setiya, p. 336).

Something like Setiya's view must be factored into a thicker notion of rationality for cities. Particularly with precarious questions such as "What is it that a city desires?" it is imperative to consider the implications of actions taken in the name of efficiency. For example, if a leader deems it more appropriate for a city to tear down a historic neighborhood to build a highway than to preserve the neighborhood because the highway will make travel more efficient, something seems to have gone wrong. Either the city has done something that it did not want to do, or the city has done something that it wanted to do but should not have wanted to do. In both cases, though, a notion of rationality that declares it irrational to pursue a desire the city ought not have would have deemed the project irrational.

The question of what it is for a city to want something adds a layer of complication to discussing rationality for cities. In the Easwarian view, a city wants something when practically everyone in the city wants it, with some issues found when some individuals have desires that are very different from general city desires. However, Easwaran claims that people in the city will at least want clean air and water. He also claims that not everyone may be aware that they share a desire pre-implementation (Easwaran, sec. 5.2). When a city does something for part of the group, Easwaran thinks of it as similar to akrasia. In the case of the highway construction ultimately displacing a large number of people, the city did not want the project to be completed because certainly at least the people living in the affected neighborhood did not want their homes destroyed.

However, at least some of the time, cities want things that they ought not want. Easwaran concedes that this means that a city could act rationally in his view without acting morally (Easwaran, sec. 7). If everyone in a city wants to allow murder to be completely legal, surely doing so could not be rational. If we take another view of what it is for a city to want something, it is nonetheless possible that a city would have some desire for a thing that is morally heinous.

I do not have a particular theory of what it is for a city to want something, but I think it tends to be something we can tell. A city could want something without everyone in the city wanting it (for example, all but one person wanting to build a particular park), and I think everyone in the city could want something without the city itself wanting it (for example everyone wanting to pollute the air without reservation).

One could think that a city desires something when the governmental systems in place for a city give a certain indication. However, an example where this does not seem to work is in the case of a certain candidate being elected mayor that most people in the city do not want to be elected. Not everyone in a city is eligible to vote, and even those eligible to vote are not always able to or do not always vote.

The particular nature of these desires, though, is not something I can tangibly articulate. Further discussion on what it is for a city to want something would be helpful for understanding rationality for cities.

Another important question is what it is that makes up a city, and for Easwaran, that comes back to people and geography. Easwaran's definition of a city is helpful because it includes everyone who is geographically involved with a city, not just those who live within a certain border or who are eligible to vote in a certain district. I think something like the Easwarian definition of a city with the potential addition of the interaction of people, geography, and infrastructure seems right, but further discussion is warranted. However, this argument can be understood without having a conclusive answer to the question of what a city is or what, in principle, it is for a city to desire something.

As Setiya discsusses, even people who are extremely virtuous are not virtuous because they never have malicious desires, but they simply do not respond to their malicious desires (Setiya, p. 336-337). Similarly, a perfect city is not a thing that exists, but a generally virtuous city is plausible. Such a city has systems in place for malicious desires to come into existence but not be realized. The case where the city votes to do something that is immoral is still possible, and it is difficult to reconcile the need for citizen input with the need to act morally. However, this discrepancy could be thought of as a necessary irrationality; sometimes a city acts irrationally and/or immorally, but not having the ability to do so would mean there are other problems in existence. Cities having the power to do bad things does not mean that they should. This issue also warrants further discussion.

Problems like this are part of the reason rationality is difficult to justify as a sole arbiter of what a person or a group ought to do, and within rationality, a single notion is unlikely to be universally applicable. Rationality for cities is something that can help cities analyze past decisions and maybe even inform future decisions, but it may not be particularly effective in helping cities make specific decisions. It could indicate larger trends in systems that make cities generally rational or irrational, though.

Rationality does not have to be the sole guiding principle in order to be helpful. This notion of rationality that is sensitive to whether desires ought to be pursued could be a tool in the toolbox for people leading cities or simply trying to be good residents. It is something of a nebulous concept in that honing in on what cities do is a difficult process. Cities constantly change and evolve. Someone who is part of a city at one point is not necessarily part of it at another point, and the underlying values guiding cities change with the distribution of power.

Different Roles for Notions of Rationality

I do not mean to say there is no role for means-end rationality, nor do I mean to say there is never a role for means-end rationality for cities. Rationality is unique to each kind of unit, and different notions of rationality have different purposes. Rationality is also unique to its context, and the context I have explored here is the kind of rationality that may govern what we ought to do and what cities ought to do. This kind of rationality, I believe, is appropriate for incorporating morality in the way I have argued here. It is possible that a city could want two things, one of which is moral and the other of which is not. I assert that the city must pursue the desire it ought to have in order to act rationally. Just because a notion of rationality that incorporates morality is meaningful in some contexts, I do not want to assert that such a notion is the only useful one. Means-end rationality is important to understanding many fields; I simply think that in the philosophical sense, a notion of rationality for cities should not conflict with a notion of morality for cities, and a thicker notion of rationality is often appropriate for meeting this requirement; city leaders need not feel obligated to make decisions that may be effective ways to gain certain ends but that conflict with morality. In other contexts, it does not seem to be quite as necessary or useful to be concerned with morality when discussing rationality. Means-end rationality is helpful for modeling behavior and decision-making; it helps us understand the world around us. Just because someone is acting rationally does not mean they are acting morally, and not every notion of rationality needs to be intertwined with morality.

All of this is to say that different notions of rationality do not need to be mutually exclusive; each notion simply must fulfill its respective purpose. The Easwarian view of rationality for cities meaningfully assess whether a city is achieving its goals. My view of rationality for cities assesses whether a city is achieving its goals that it ought to have. These two standards are valuable in different contexts. A leader ought not necessarily be praised for pursuing a means-end efficiency for a city, but perhaps ought to be praised for efficiently pursuing goals the city has and ought to have. On the other hand, this incorporation of morality may interfere with efficiency, and sometimes, an Easwarian evaluation for a city might be most useful (ex.when a decision must be made quickly in the case of an emergency).

In cases where means-end rationality and a thicker notion of rationality conflict, saying one is right and the other is wrong is not necessarily required. Rather, one can evaluate an action using the notion of rationality that makes the most contextual sense.

Conclusion

In this paper, I have argued that the way we talk about rationality for cities indicates at least some use in discussion rationality for cities, and I have argued that cities act rationally when efficiently pursuing desires they ought to have.

Rationality alone is not an answer, but a notion of rationality that dismisses malicious desires is more compatible with other principles that ought to guide cities than means-end rationality alone.

This notion of rationality is hopefully compatible with morality, justice, equity, sustainability, and all the other qualities we think of when considering what makes a city good. Those who still find discrepancies among these would be valuable in nuancing the discussion so that a notion of rationality for cities that best promotes healthy cities can crystallize.

Should Cities Be Concerned With Rationality?

Similarly to Setiya, M. Christine Boyer expresses a concern with unchecked efficiency. In the contexts of city planning in the United States, she argues against a kind of rationality focused only on increasing capital in Dreaming the Rational City: The Myth of American Urban Planning (Boyer, 1983). I should note that this is not exactly a discussion of rationality in a philosophical sense, but Boyer's work provides context for understanding the history of "rationality" for cities. Even though my discussion differs from this less literal notion of rationality, it is important to discuss how notions of philosophical rationality might interact with pre-existing discussions.

Boyer discusses the early goals of city planning in the United States to bring rational order to the physicality of cities and argues that the interplay of capitalistic desires and the search for rational (i.e. optimizing capital) cities harmed the early development of city planning in the United States. Ultimately, Boyer concludes the book emphasizing the problems with trying to bring perfect rationality to city planning without enough input from existing structures in cities and communities impacted (Boyer).

It is important to note that Boyer's commentary focuses on American city planning and does not encompass global planning traditions. A key takeaway from the story she tells, though, is that when planners try to make things too efficient and do not have regard for the nature of the ends they are pursuing, the input of the public is neglected and resources are wasted on projects that are ultimately failures. Even with a notion of rationality that involves pursuing only desires the city ought to have, prioritizing only efficiency in pursuing those desires could lead to neglect of public input and thorough, patient processing of residents' concerns.

Prioritizing only rationality for cities would likely lead to frustration; actually thinking of the city as a rational unit when planning the city's future may not be particularly practical. Even if some decision is theoretically rational for the city, making that decision could be destructive if the decision is made without proper consideration of and consultation with the communities affected. Boyer discusses that in trying to optimize the physicality of cities, early planners in the United States set unrealistic goals; the existing structures within cities make complete optimization unrealistic (Boyer, p. 282-290).

Something that can be useful about rationality for cities is the idea that cities are entities of their own, and no one person within a city should be concerned only with their own interests. Rather, community awareness of larger desires of the city can help residents understand the importance of engaging with their communities.

This is applicable to leaders as well as all members of the community. The city depends on many systems to function together, and no one person or entity within the city has desires overriding the desires of others. Rationality for cities can analyze trends over time and help figure out the kinds of decisions that are most useful for a given city.

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Improving Thermal Neutron Scattering Simulation Data

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1. Introduction

Safe operation and design of nuclear systems require accurate simulations that can predict neutron fluxes and power distribution in nuclear reactors. However, the trustworthiness of simulation output is limited by the quality of the input nuclear data. Despite the importance of thermal neutrons, which are more likely to result in fissions than fast neutrons, data regarding their scattering behaviour has been historically neglected. In order to provide the most accurate data for thermal neutron scattering it is essential to have access to a flexible range of materials at various temperatures.

One of the most common data processing tools is a modular code known as NJOY (Macfarlane, Muir, Boicourt, Kahler III, & Conlin, 2017), where two of the modules (LEAPR and THERMR) are dedicated to preparing thermal neutron data. However, while these modules can often prepare data for abitrary materials, there are other calculations for which LEAPR and THERMR are limited to hard-coded values in the source code. This reliance on hard-coded values restricts NJOY to only six materials for coherent elastic scattering[1]. Furthermore, these hard-coded values are sourced from various papers from the 1960s and are now outdated. Graphing the coherent elastic scattering cross sections results in "Bragg peaks" which are sharp jumps in the cross sections that occur at various energies. Comparing the graphs generated from the original and modern physical constants reveals that updating the scattering constant values scales the height of the Bragg peaks and updating the lattice constants shifts the Bragg peaks on the energy axis. These corrections constitute an improved representation of the coherent elastic scattering process. Implementing these corrections allows for more accurate predictions of thermal neutrons and more reliable technology.

2. Technical Background

Thermal neutrons can interact with materials in one of four ways, each collision is either elastic or inelastic and coherent or incoherent. An elastic collision means that total kinetic energy is conserved during the interaction. Since thermal neutrons do not have sufficient energy to break molecular bonds, they typically scatter off of much larger targets than fast neutrons (i.e., a full lattice as opposed to a single atom). Thus, the size of the target is much larger than that of the neutron, causing the neutron to lose little to no energy in an elastic collision. In an inelastic collision, the total amount of kinetic energy is not conserved, but is instead lost or gained in the creation or destruction of phonons in the target material. Each elastic and inelastic collision has a coherent and incoherent contribution. Material composition and material structure dictate whether coherent or incoherent scattering will dominate. Some nuclides have inherent preference towards coherent or incoherent scattering. Those with preference towards coherent scattering have a larger bound coherent scattering cross section, σ_{coh}, and a smaller incoherent bound scattering cross section, σ_{inc}. These material properties are used when computing both the elastic and the inelastic scattering cross sections. Whether a neutron will scattering coherently or incoherently also depends on material structure. Coherent scattering is more likely to occur when the target atoms are arranged in such a way that the scattering causes the resulting waves to constructively amplify or destructively cancel each other. Incoherent scattering is more likely to take place when the atoms are not arranged in a regular way and the resulting waves are more chaotic.

When the coherent bound scattering cross section σcoh is sufficiently large and the material structure is ordered, then computing the coherent elastic thermal neutron scattering cross section is desired. This data can be prepared using the NJOY nuclear data processing code.

The LEAPR module outputs the Bragg vector associated with a specific material. This vector contains weights and energies that can then be used to plot the Bragg peaks for the material with this equation. The coherent elastic cross section (integrated over all angles) is

$$\sigma_{elastic}^{coh}(E) = \frac{\sigma_{coh}}{E} \sum_{E_j<E} f_i \, e^{-4WE_i}. \tag{1}$$

where σ_{coh} is the material scattering constant and f_i are the weights of each Bragg peak,

$$f_i = \frac{2\pi\hbar^2}{4mNV} \sum_{\tau_i} \left|F(\tau)\right|^2. \tag{2}$$

The weights are computed as a function of τ^2, the reciprocal lattice vector lengths. The reciprocal lattice vector lengths for a Body Centered Cubic (BCC) Lattice are

$$\tau^2 = \frac{3}{a^2}(l_1^2 + l_2^2 + l_3^2 + \frac{2}{3}l_1 l_2 + \frac{2}{3}l_1 l_3 - \frac{2}{3}l_2 l_3)4\pi^2 \tag{3}$$

and the reciprocal lattice vector lengths for a Face Centered Cubic (FCC) Lattice are

$$\tau^2 = \frac{2}{a^2}(l_1^2 + l_2^2 + l_3^2 + l_1 l_2 + l_1 l_3 + l_2 l_3)4\pi^2. \qquad (4)$$

3. Current Methods

NJOY is a modular code developed and maintained by the Los Alamos National Laboratory that produces scattering cross sections using data from the ENDF-4 through ENDF-6 legacy card-image formats. Two of the twenty three modules (LEAPR and THERMR) deal with thermal neutron scattering. These two modules have significant redundancies of code, they both take in information about a material and output the corresponding Bragg vector for coherent elastic scattering. The user may chose to use LEAPR and THERMR alone or together. When THERMR is used alone for coherent elastic scattering, it interpolates to find the Debye-Waller Factor for the material at the given temperature. This Debye-Waller factor is a temperature dependent term related to the average displacement of atoms from their lattice sites and is necessary to accurately compute the bragg vectors for coherent scattering. However, this interpolation produces unreliable values that affect the accuracy of the Bragg vector. In addition, THERMR is only able to compute the Debye-Waller Factor for three materials that have a hexagonal crystallographic structure (Graphite, Beryllium, and Beryllium Oxide). Even for these materials, THERMR has the same inaccurate material parameters as LEAPR. Using THERMR and LEAPR together requires a phonon distribution which can be difficult to obtain accurately.

Ideally, a good thermal neutron scattering data processing code would have access to a wide range of materials. LEAPR is only able to provide coherent elastic cross section data for six (Graphite, Beryllium, Beryllium Oxide, Aluminum, Iron, and Lead). By only permitting preparation of coherent elastic scattering for some materials, NJOY is limiting the scope of nuclear systems that can be accurately simulated. Rectifying this shortcoming requires allowing for more materials to be represented, and improving the physical parameters that describe existing materials. LEAPR calculates the scattering cross sections of the materials based off of material parameters: mass, scattering constant, and lattice constant(s). In order to produce valid results, it is essential that these parameters are accurate. For all materials considered in LEAPR and THERMR, these parameters are hard coded in the source code. These hard coded values are not clearly marked for users to change, and many of them are incorrect up to an order of magnitude. This misrepresentation of data drastically changes the appearance of the scattering cross section, and must be corrected in order to accurately calculate the coherent elastic scattering cross sections.

4. Improvements

Five of the six materials available in LEAPR have errors in at least one material parameter, but the most significantly affected materials are Lead and Iron.

The original material parameters used in LEAPR and THERMR come from various papers from the 1960s. The improved Lead lattice constants come from Haas (Haas, Tran, & Blaha, 2009). Both cross scattering constants come from Sears (Sears, 1992).

Pb		
Parameter	Original	Corrected
a-Lattice Constant (Å)	4.94	4.912
Scattering Constant	1	11.115

Table 1: Lead material parameters

Fe		
Parameter	Original	Corrected
Scattering Constant	12.9	11.22

Table 2: Iron material parameters

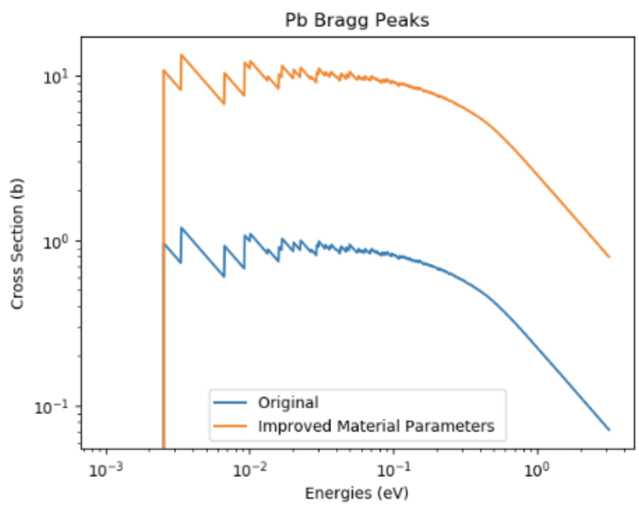

Figure 1. Lead Bragg peaks

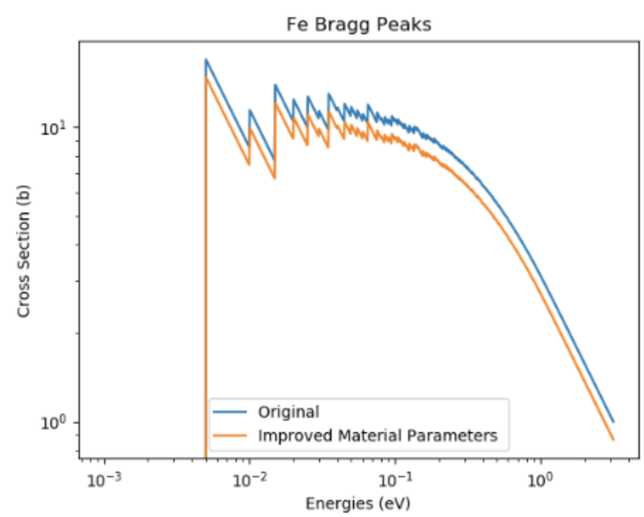

Figure 2. Iron Bragg peaks

Bragg peaks are a graphical representation of the Bragg vector of a given material. The scattering cross section is plotted on the y-axis and the energy levels are plotted on the x-axis on a loglog scale.

From the Bragg peaks (Figure 1 and Figure 2) it is clear that a change in the scattering constant causes significant shifts in the

Bragg peaks. An increase in the scattering constant corresponds to a upward shift on the cross section axis. These shifts align with the equations describing the Bragg vector (Eq. 1). When the cross section is graphed, the scattering constant acts as a scaling term and the Bragg peaks are scaled proportionally to the increase in the scattering constant from the improved material parameter.

For a material with an incorrect a-lattice constant, an increase in that material property would correspond to a shift leftwards on the energy axis. This change comes from the weights used to compute the bragg vector. The weights, f_i, in (Eq. 1) are a function of the reciprocal lattice vector lengths, τ^2, (Eq. 3 and Eq. 4). For both FCC and BCC lattices, the reciprocal lattice vector lengths are proportional to 1 over the a-lattice constant squared. Therefore, a material's a-lattice constant is inversely proportional to the energy.

5. Conclusion

Accurate simulations of thermal neutrons are important for the safe operation and development of nuclear reactors, but the accuracy of data describing their scattering behaviour is lacking. The data processing tool NJOY is designed to prepare thermal neutron scattering data for simulation input. However, when preparing the data for coherent elastic scattering, there are several limitations and errors that affect the accuracy of results. For the LEAPR and THERMR modules in NJOY, the code is limited to hard coded material parameters. These hard coded parameters only exist for six materials, and are incorrect up to an order of magnitude. Graphing the Bragg vectors output from NJOY for Lead and Iron reveals that updating the outdated material parameters with modern values results in a significant changes in the Bragg peaks. Changing the coherent elastic scattering constant scales the peaks, and changing the a-lattice constant shifts the locations of the peaks on the energy axis. These corrections constitute an improved representation of the coherent elastic scattering process. Implementing these corrections allows for more accurate predictions of thermal neutrons and more reliable technology.

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