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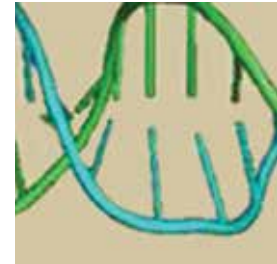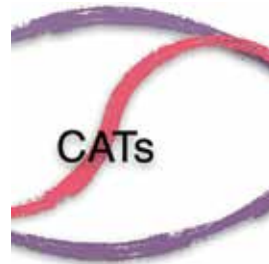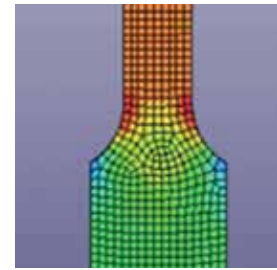
# Berry Summer Thesis Institute

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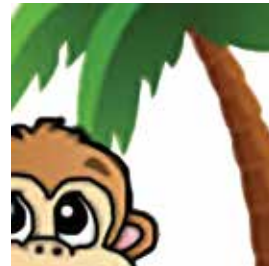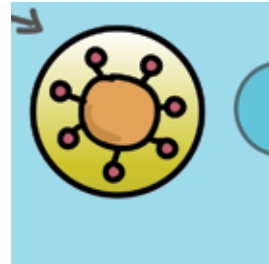
**University *of* Dayton**

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*proceedings*
2019

# Proceedings 2019
## Berry Summer Thesis Institute

Dear Reader:

On August 1, 2019, a group of faculty, staff, friends, and family attended the seventh annual symposium for the Berry Summer Thesis Institute (BSTI). Those in Sears Recital Hall that day, including University of Dayton President Eric Spina, witnessed the largest-ever BSTI cohort present the early stages of their Honors thesis research. The scholarly and creative projects included in this volume of the Proceedings range from an analysis of how short chain fatty acids affect the progression of Listeria infection to the creation of a children's book promoting sustainability, whose design and production are intentionally aligned with sustainable practices. This particular cohort includes students from every academic unit on campus: the College of Arts & Sciences, the School of Education and Health Sciences, the School of Business Administration, and the School of Engineering.

This collection once again reflects the Honors Program's goals for the BSTI: (1) to introduce rising juniors to peer review and publication; and (2) to begin the process of contributing to knowledge or producing original creative works. As the director of Honors, I am especially grateful for the friends and alumni who continue to support the Berry Summer Thesis Institute. In particular, let me express my sincere gratitude to Mr. John W. Berry, Jr., Mrs. Shirley Berry and the entire Berry family for their continuing support for the University of Dayton Honors Program. I also want to extend my thanks to Dr. Nancy Martorano Miller for her leadership of the BSTI; Ramona Speranza for producing the Proceedings manuscript (for the final time—as Ramona retired in Fall 2019); Laura Cotten Howell for her assistance in the area of professional development; to Maria Ollier Burkett for facilitating the connections with community partners that allowed our students to engage with the greater Dayton community; and Jill Talley for her administrative support of the Institute. Please enjoy the work of these talented UD Honors students.

Best,

John P. McCombe, Ph.D.
Director
University Honors Program
University of Dayton

# TABLE OF CONTENTS

**Page**

# ACKNOWLEDGEMENTS

**Page**

# He, Him, and the Father:
# A Philosophical Fiction Novella

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## Introduction

I wanted to create a novella with a focus on the philosophical themes of existentialism and gender. My novella is inspired by Albert Camus' *The Stranger*, *The Fall* and *The Myth of Sisyphus*; Osamu Dazai's (a famous Japanese author) *No Longer Human*; Samuel Beckett's famous absurdist play, *Waiting for Godot*; and other works referenced in my working bibliography. All of these works embrace the themes of human existence; or rather, what does it mean to exist as a human. The characters, relations and themes of my future novella are built upon the foundation laid out by these creative and philosophical thinkers: the philosophy of existentialism.

The novella has primary characters that are distanced from humanity and regular relations. The three primary characters each embrace a different aspect of existential philosophy, such as genres of nihilism and absurdism. These philosophies will be fleshed out to achieve a working narrative of the prime motivation, and true essence, of each of the characters. For example, the main character, Tyler, expresses the notion of nihilism. He does not comprehend emotion, is indifferent to the world around him and tries to explain everything rationally. Although, as the narrative progress and he witnesses the absurdity of the world and the rationality it lacks, he is driven to a depressive crisis.

The novella will focus around the themes of depression and meaning in a meaningless world. Progressively, Tyler sees the world become less rational by the events that occur. I hope to flesh out all of the prominent aspects of existential philosophy: other characters express optimistic nihilism and absurdism. Their relations and ways of living come to clash with each other's mentality. Throughout the novella, Tyler questions his meaning of existence, the reality of the world and suicide.

The novella consists of individual chapters that focus on a specific theme. For example, the first chapter develops themes of objectification and religion. It is also written from the perspective of an altar, an inanimate object (to objectify those in its sight).

To understand this concept, I have included the first chapter.

# Chapter 1

# Here I Am

*"But for what purpose was the earth formed?" asked Candide.*

*"To drive us mad." replied Martin*

Vibrations took hold, harmoniously. The walls ever so slightly rang as each nail and pew kept its place. In contrast, footsteps, muffled by ruffed carpet, gradually approached from behind. Upon their arrival, the touch of cold hands froze the vibrations away, and the ambiance was now approaching a low hum. Hands, still hidden from sight, groped from behind. They were searching for a book. The weight of said book caused relaxation as it was lifted out. It was opened and spread across the top. Once the proper page was presumably found, dewed skin grazed from above. Wet from the turning of pages. The print of moisture was chilling, but it dissipated quickly. Although the memory lurked until the skin was dry from continuous touching, and rubbing, of the pages and of the wood that surrounded.

The hum proceeded to escalate once more. Although the vibrations were controlled by the now dry hands. Near the front, the door was pushed open as a mother and daughter entered into common domain. The doors shut before the warmth of the light reached the hands; neither of us felt warmth. The mother approached until her eyes escaped from sight. They were brown, as always, and they were looking above the hands. The man of the hands was now in front, and he hugged his beloved. Halfheartedly, however, as one of his hands never left the wood. He was still controlling the harmonious vibrations, while keeping his eyes always hidden.

While the touch from his hand did not cease, his daughter was in plain view. On the second pew back, is where she always sat; however, instead of to the right by the aisle, she now sat farthest left. She was under a cross. The man who was hung across it had a limp neck and seemed to stare down upon her, in pain. Her eyes were green, queer, but she rarely put them into sight. She was always looking down or under the cross. Never to the hands; therefore, her gaze remained largely uncaught. The mother was let go and went to her daughter. Her name was unknown. The hands were now much more prevalent, we were one once again. The force of his body caused much distress. He was no longer needed to dismiss the vibrations. All was still.

Not before long, a crowd was beginning to be pulled through the doors in front. Most prominently was Tabitha Linn. Although she was only prominent due to the fact that the hands of the eyeless man always addressed her. He always noticed some members of the crowd, rather than the others. When the rituals were over and the day done, people would come near and kneel. The man would come kneel beside them, in such a way that his eyes remained unseen. In this exchange, whispers were always shared between the fallen and the man. Tabitha always came to kneel. When the whispers were drowned by the clatter of the hall, the man always spoke their name and welcomed them to their new home. Long ago, Tabitha's name was uttered for the very first time. Back then, she was whispering about her father. Unlike all the others, she never whispered to just the man, but to us. She knew this place, she knew it well.

She sat in the back, among all the other women besides the queer-eyed the girl. In the front Richard Winnigan sat with numerous others that have not yet had a name. Nothing is more pleasant then hearing a name for the first time. The herd is always happy, the newly named is always crying, and their tears are always wiped away by the hands that stop the vibrations. Sometimes, if they weep hard enough, the tears are carried by the hands and dewed skin grazes from atop. Alas, no new names have been delivered in quite some time. Some no names don't even show their eyes. They never look at us. Although this is exacerbated by the queer eyed one, and by the hands that are constantly felt.

However, Tabitha Linn has eyes that one never forgets, as they never look away. She deserves the attention of the limp necked man much than the lonely girl upfront. Although the hands above might disagree: he loves his queer-eyed daughter. They, as a family including the mother, always walked out last. Before the darkness consumes the hall. These times are quite lonely. Only the limped neck man is here then, but his gaze is fixed away like everyone else. In contrast, the times with the herd and the hands are quite joyous. Everything is seen, everything is heard, and everyone is just that.

When everyone was seated with the pews, the named and unnamed alike, the man above with the now hellishly dry hands began to speak. The congregation rose, like a colony of ants with one mind, and began to sing. Everyone partook to produce a rhythmic hum, except for Zachary Taylor. He was, as the hands professed in a recent meeting when the lights were on, the mayor of the people. He always mouthed the words to the hymns without fail. Whispers sometimes graced the pews saying that he's the devil, while others whisper he's a quite decent man, and the rest don't utter his name to supposedly avoid his work in the hall. Nonetheless, all the people treated him well, but no one seemed to notice he always mouthed the words. Even the queer eyed girl sings, albeit almost as if it springs from forced memory and the lack of free will. Although while she could be heard, she rarely ever looked towards us.

Tabitha Linn was handing out song books to those not participating, and they started to sing. She always seemed to raise moral when the hands above were not speaking. She had a lovely voice, and she didn't even need a song book. In the front, Richard Winnigan was shouting the lyric and dancing, thanks to the balance offered from his cane. Sometimes people raise their hands to the roof, but never put on a show quite like this. It would not have surprised the congregation if he died right there. He seemed ecstatic.

The man eventually started talking, and the whispers, singing, and voices halted to silence. "What a great day to gather here, folks." He began.

"Amen!" The collective unison was quite the achievement considering the packed hall.

"Although, even in times like these, we still need God more than ever." The herd twinkled. "Would anyone like to lead the prayer requests?"

"I will, Fadder!" Richard Winnigan's hand shot out of his loose short-sleeve button up shirt. He always talked different from the rest of the crowd. Some even seemed displeased every time he spoke. Perhaps because he talked different, acted different, looked different, perhaps the amalgamation of everything about him, or maybe that was just how things are. However, he was surely loud. The crowd always whispered about him before singing started. Supposedly, a man named Arnold convinced him to sit in the front. While many think Arnold didn't do that to poor Richard Winnigan, all of them seemed to think he should not sit behind people due to the spit when he yelps. Nonetheless, he was sitting in the front, the contingencies didn't seem to matter to anyone. Everyone was happy, including Richard Winnigan, when everything worked as it should.

"Well go on right ahead, Richie. Just remember, God don't give you anything you can't handle." Richie was very happy at the man's reply. He stood up and turned around.

"I'm official retired!" He exclaimed as he raised his hands for all to see. The men behind him waited for him to turn around before wiping their faces and clothes.

The man's hands came thudding down, the sound echoed slightly. Vibrations, once again.

"Well," the man took his time to draw it out, "I'll be. Did y'all know that? But let's hold on now, Richie, who is going to be at Romana's to get me my coffee every morning?" The crowd laughed, some chuckled. "He's been working there for 17 years. Bless your heart, son. Let's give Richie a big round of applause." Even the queer-eyed girl clapped, but she didn't stand like the rest. For a second, she revealed her greenness. The applause didn't last long. Zachary Taylor, the supposed mayor, stood up and buttoned his suit jacket.

"Preacher, I just wanna thank the Church for givin' me a home and for lettin' me know the good Lord. I wish the best for this here church." He waved, turned around, waved, and sat down. The crowd behind placed hands on his back for blessing.

Diane Winnigan, Richard Winnigan's mother, feebly raised her hand. She was as ancient as ribs and apples, and everything that came with. Although, even with her age she still managed to take care of her beloved son, or so the whispers implied.

"Diane, empty your heart." The man seemed sympathetic, and the words seemed to drag on.

"Well Richie's already been so excited, and he already mentioned it, but I just wanted to thank God for what the Church has givin' us. I know he's loved it, and bless this Church!"

"God is great!" Richard Winnigan yelped. The man gave him a gesture with his hands. It was felt. The crowd applauded for a short time.

Silence followed, the crowd started to whisper, about Richard Winnigan to Zachary Taylor to who is paying for the hall's toilet paper. However, after some time of fellowship, Tabitha Linn raised her hand. Everyone turned around and she did not stand.

"Just pray for my family. I've been trying to get my son and his family in the Church again, but I trust God has a plan for em'. Even if I don't get it." The crowd was silent. The queer-eyed girl went red.

"Tabitha, ya couldn't be more right. He most certainly does. Everything in our lives has meaning all leading to this great, great world we have." The man's grasp was tightening. "I myself have an unspoken request, He knows what it is. Amen?"

"Amen!" Everyone, except for one, chanted.

An older man, name unknown, raised his hand and was prompted by the man.

"John. Go ahead." His name was John. Another name to another face. John stood and removed his hat.

"Well, sir, I juss wanna say a prayer for our world and our military. It seems like it's gettin' worse n' worse every single day. But I know God's got a plan for it." He sat.

"That he does, that he does. And, yes. Everyone please keep the world and military in your prayers. We can only imagine." The herd was silent, the man took his time. "Well, if no one else has any prayer requests, let us bow our heads.

Everyone bowed their head, insects to their queen. Except for one. The queer eyed girl was staring right at us, at the man. The man started his prayer, but the gaze was too distracting. Focusing on the girl, came a revelation. The prayer was still being said, and her eyes were blue.

"Amen." The man said, and it was done. The girl's eyes snapped back down. She didn't have queer eyes. They were just blue, formerly never fully revealed.

"Amen!" Said the crowd.

"Well y'all, I'll be speakin' on what God has put on my heart recently. Open your Bibles to Genesis. Chapter 22." The man's hand became moist again as he flipped to the page and retreated his touch from the book. The others, most of them, did the same. Tabitha Linn gave out bibles from her pew to her feline neighbors. "Now, I'm sure we all know the great story of the Father of Faith, but, as with most things, I do feel that we may gloss over the importance of what Abraham did." The crowded nodded. A man in the fourth pew back took off his tie, and some women began fanning themselves. "Let us read. Verse 1. And it came to pass after these things, that God did tempt Abraham, and said unto him, Abraham, and he said . . . behold, here I am. --"

The man's voice was much smoother when he read his verses. It was more graceful, perhaps more purposeful, than his normal rhetoric. The crowd followed along with each verse, even the blue-eyed girl. Her eyes drifted as she followed the page. While she was, for once, participating in the actions of the crowd, she stood out even more. She sat along with her mother, near the front among the men. Her hair was long, but not particularly fanciful like the other women in the crowd. Also, instead of a dress, she bore slim white dress pants with a fitting white dress shirt tucked in. She was quite pretty compared to the older crowd, though she never looked at us. She looked pure; however, in contrast to this theme, she wore a black beaded bracelet that stuck out from her white attire.

"And Isaac said unto Abraham, his father, and said, 'my father.' And Abraham said, 'Here am I, my son.' Then, Isaac said 'behold the fire and the wood, but where is the lamb for a offering? " He was continuing with his verses. The blue-eyed girl, or perhaps a woman, raised her leg across her knee which brought into vision one pink sock, barely visible between the start of shoe and end of the white leg. She had stopped reading, and her chapter was closed. She was looking at her mother.

"Abraham built an altar there, n' laid the wood in order, n' bound Isaac his son , and laid him on the altar upon the wood." The man flipped the page. Moisture, once again. The crowd flipped the page. The blue eyed woman was the center of all interest. She looked at us, once more. Unlike all other women in the crowd, her lips were not hellishly red. She was peculiar.

Richard Winnigan was opening up his phone to check the time. He was much more relaxed than she. Although in the middle was Zachary Taylor, he was looking at us — perplexed — then to the crowd, then left and right to his neighbors. An unknown man must have remembered his hat was taken off for prayer, and he fitted back upon his moist, sweaty head.

While reading, the man kept tapping beside the weight of the book. It started quite slowly, then grew faster, then rapid. The humidity inside the hall was accumulating throughout the service, and it reached its peak at this time. Each tap caused a vibration, and each vibration, jiggled the minute layer of resting water. He reach inside, hidden from sight as usual. He touched inside until he retrieved a white cloth that he groped with his hands. They were no longer wet.

"Here am I — " The blue-eyed girl's face was stained like an anointing gone too far, dripping down from the head. She was no longer looking at us. Though the limp necked man did not budge his gaze. She was objectified under the holy presence. "And he said, Lay not thine hand upon the lad, neither do thou any thing unto him. For now I know that thou fearest God, seeing thou hast not withheld thy son, thine only son from me. Amen." The crowd looked and bowed their head, simultaneously.

He began, "Let us pray. . . Let me not, Oh Lord, be puffed up with worldly wisdom, which passes away, but grant me that love which never abates, that I may not choose to know anything among men but Jesus, and Him crucified."

"Amen." Cumulatively, it was said. By everyone.

"Well everybody, all minds clear? Any comments, questions? Answers?" The man of the hands waited for the response he suspected. The feeling of tapping was hovering from above. "We'll begin our break for fellowship shortly, gather your thoughts and we can reconvene after some of Romana's coffee in the back. But first . . ." His hands lifted up. "Mayor, would you like to come up?"

As if expecting the invitation, the Zachary Taylor bolted up and hurried to the front, by us. He smiled, and he waved back to back. He eventually stopped and turned to the crowd. The blue-eyed girl looked up at him.

"Wasn't that a great service y'all? And still more to come! What a great place to be this Sunday. Amen?"

"Amen!"

"Well let me tell y'all about a little ole' thing me and the preacher have been cooking up. Richie, would you like to join me?" Richard Winnigan sprang like flame with purpose out of seat, and after hugging

his mother, he joined the mayor upfront. Their eyes were hidden facing the crowd. "Like I said, we've been planning a little ole' thing just for you, Richie. Y'all, make sure you're payin' attention. After evening service the Church will be staying open in honor of Richie's surprise retirement party!" Zachary Taylor rubbed Richard Winnigan's shoulders as he finished his speech. "Why, do you want to say anything to these kind people, Richie?"

"I'm so happy and official retired! I can't wait to sit down on my Lazy Boy and sleep in till I just don't wanna sleep no more!" The herd cheered, and the blue-eyed girl clapped.

<p style="text-align:center">***</p>

## Conclusion

This chapter emphasizes the biblical story of Abraham, as well as objectification (major themes that are present throughout the novella). This chapter was written initially with free writing that developed as ideas were written and remolded. Further chapters follow from that same process, as it is my preferred style of prewriting.

## Acknowledgement

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# Toward a Theology of Mental Illness: Spirituality, Religion and Their Effect on Mental Health

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## Abstract

The fields of theology and psychology both aim to understand what it means to be human and strive to unpack the human experience. This study explores the ways in which religious traditions and spiritual practices, particularly those of Judaism, Christianity and Islam, may impact an individual's mental health. Archival research was conducted, studying the writings of theologians and social scientists who have written about this integration of religion and psychology. This literature review is a summary of all of these writings, giving a deeper understanding of the ways in which individual Jewish, Christian and Muslim theologies intertwine with mental health.

## Introduction

This study of religion, spirituality and psychology aims to examine the impact that practicing Judaism, Christianity and Judaism has on young adults, aged 18-25, in the United States. The field of the psychology of religion may as well be called the "psychology of Christianity," as the majority of research done in this field uses strictly Christian subjects, traditions and practices. The findings in this exclusively Christian research are then most often applied to religions as a whole, due to the misunderstanding that all religions are unitary (Watts, 2017). Growing globalization and individualism in the world calls for studies to look more closely at faith communities and religions outside of Christianity. My hope in investigating Jewish, Christian and Muslim spiritualities is to create a more inclusive understanding of how these religions impact individual mental health in the United States.

## History and Definitions

Throughout academic history, the fields of Theology and the Social Sciences have crossed paths in numerous ways. Until the 1970's, the majority of world religions did not trust the social sciences. Additionally, the social sciences dismissed religion and spirituality as a form of neurosis, following closely Sigmund Freud's notion of faith and spirituality. Freud's definition of religion is as follows: "A system of wishful illusions together with a disavowal of reality, such as we find nowhere else … but in a state of blissful hallucinatory confusion" (Freud, 1927). Through this definition, it is clear that the understanding of religion and spirituality through the lens of psychology was, for a long time, incredibly biased. Psychology has accused religion and spirituality of intolerance, social repression, mental illness and strict dogmatism (Ellis, 1986). On the other hand, religion has also accused psychology of arrogance, amorality, selfishness and elitism (Vitz, 1977). Through my research, my goal is to move beyond this bias and look objectively at the effects of practicing religion and spirituality on an individual's mental health.

Defining terms proves itself to be quite the task. Religion and spirituality are both ineffable, meaning these words hold phenomena beyond the senses and, thus, beyond language. In studying numerous definitions of both religion and spirituality, as well as their origins, there is a clearer understanding of the hazy connotations these words often carry with them. If you think now of the word "religion," you may begin to immediately build a definition given your own personal understanding or experiences. For example, the majority of individuals would begin to connect the word "religion" to words such as "traditional," "organized," "fixed," "systematic" and "objective," just to name a few. Similarly, the word "spirituality" carries with it its own undertones. These may include words such as "personal," "new," "spontaneous," "informal" and "subjective." All of these connotations show up in the academic definitions created by theologians, psychologists, sociologists and anthropologists.

If we were to stop here and accept these almost competing definitions of religion and spirituality, it would miss out on something incredibly important that underlies the meaning behind both religion and spirituality: "the sacred." Because we cannot fully grasp the concepts of religion and spirituality, we can instead look at their relationship to one another, which is this idea of the sacred. Robert Emmons defines the sacred as the "search for meaning, for unity, for connectedness, for transcendence and for the highest of human potential" (Emmons, 1999). This sacredness is present in both religion and spirituality, thus uniting them together. Psychologist Kenneth Pargament gives concise definitions of religion and spirituality as follows: Spirituality is defined as "the search for the sacred," and religion is defined as "the search for significance related to the sacred" (Pargament, 1999). Understanding spirituality and religion in the terms of Pargament allows for both religion and spirituality, but most notably religion, to be richer and more dynamic rather than narrow in its meaning (Rican, 2004). In this research, then, the terms spirituality and religion will both be used in conjunction with one another.

William James (1842-1910), often referred to as the "Father of Psychology" had an early relationship with religion and mental health. He was the first academic to discuss religion and religious experiences and separate from the field of theology. James, himself, suffered a religious and spiritual crisis due to his own struggle with, what we would today call, depression. For James, "religious experiences were not 'supernatural,' rather they were a natural fact of human life" (Dein, 2017). In other words, James could see the significance of an experience without needing to judge if it really came from "God" or not. This idea was largely dismissed until the mid-1990's. In fact in the third edition of the Diagnostic and Statistical Manual or Mental Disorders (DSM), published in 1980, religion is mentioned 12 times. Each of these times is associated with psychopathy and mental illness. However, in the fourth and fifth editions of the DSM, published in 2000 and 2013, religious experience and spirituality are strictly differentiated from mental health and psychopathy (Dein, 2017).

## Religion and Suffering

The traditions and histories of Judaism, Christianity and Islam tell the story of a suffering people. Conflict, hardship and adversity have always been important to the teachings of these major world religions. Judaism commemorates the slavery of their people in Egypt, the oppression they have faced throughout history, and the celebration of freedom from injustice. Christianity has the symbol of Christ on the cross in his passion and death. Islam believes that suffering is the true test of faith in God. Social worker Patrick Sullivan writes of religion, spirituality and suffering as follows: "When in the throes of despair, answers are sought and there is a desperate desire for life to be different … religious and spiritual frameworks can brings some coherence to a world that has, heretofore, been experienced as chaotic at best, and, at worst, hostile" (Sullivan, 2009). Through this, it becomes clear that the stories passed on through the traditions of these major religions gives context to suffering when it may not make sense. This information is incredibly important to this study as it allows the researcher to connect with the subjects. Being aware of the context and history of religious and spiritual communities helps to eliminate exclusive, incomprehensive and narrow language. We will now look specifically at the traditions of Judaism and Islam and how practices, beliefs and customs impact the attitudes toward mental health and mental illness in these faith communities.

### Judaism

As mentioned previously, the majority of literature surrounding the Psychology of Religion uses mostly Christian samples and intradenominational samples have been rare. There are many reasons that there are very few studies surrounding Judaism and mental health, but two specifically stand out. First, there is a comparatively small population of American Jews, which makes using data from national populations hard (Levin, 2015). Second, there is no Jewish version of the US Health Interview Survey, a US version of the Israel National Health survey or questions on health in Jewish religious surveys — thus, no information from the Jewish American population is available (Levin, 2015). Due to differences in behavior, prayer, experiences, and beliefs between the Christian and Jewish populations in America, we cannot take what has been discovered about Christian faith communities and denominations and apply it to the American Jewish population. However, much like Christian communities, there is an abundance of diversity, denominationally or what are called Jewish "movements" (Levin, 2015)and there are five main Jewish religious affiliations in America: Secular, Reform, Reconstructionist, Conservative, and Orthodox (Bayes & Loewenthal, 2013).

From the little that has been studied about Jewish communities and mental health, we can conclude that having faith in the teachings of the prophets brings peace and tranquility in regard to chaos and suffering (Schnall et al., 2014). When looking at historical events such as the slavery of the Jewish people in Egypt, the Crusades and the Holocaust, one can see the striking oppression and injustice that the Jewish people have endured. Many Jewish faith communities, through these stories and events, hold true to the hope that they are the chosen people, loved and cherished by their God, and, thus, maintain a healthy mindset (Bayes & Loewenthal, 2013).

### Islam

In the present political climate, it is becoming increasingly important to shed light on Islamic communities and their stories, traditions and experiences. The 9/11 attacks brought Muslims to the center stage of America and the rampant islamophobia, social exclusion and marginalization of Muslim individuals and communities calls for a closer look at how their faith and spirituality impacts this progressively chaotic time in their history. Interestingly enough, Abu-Raiya et. al found that religious activity among American Muslims increased following the 9/11 attacks. In comparison to those who removed themselves from their spiritual practices, these Muslims experienced fewer symptoms of depression (Abu-Raiya, Pargament, & Mahoney, 2011).

Mental illness and health is often hidden in a cloud of silence in the Islamic community due to the fear of misunderstanding by clinicians and mental health professionals (Haque, 2004). There is also a stigma surrounding mental health in many Muslim communities due to the commonly held belief that mental illness is brought on by Jinn-possession, caused by one living a sinful life (Islam & Campbell, 2014). This reality in many Muslim faith communities may cause those struggling with mental illness to feel shunned.

It is important when addressing this research with Islamic communities that, again, inclusive and comprehensive language is used. Rather than looking in from the outside, it is important for research to explore these issues and realities within Muslim communities with Muslim people. The Muslim community at this time is a vulnerable population, due to the extreme hatred that is often spewed at them from the outside. In order to understand more deeply how Islam impacts Muslim individuals' mental health, we have to create a more exhaustive, tolerant and respectful environment, particularly in the healthcare system (Chowdhury, 2016).

## Neuroscience, Religion and Mental Health

Studies have shown that having a parent with mental illness increases the risk of depression for the offspring by 200 to 400 percent, although mental illness also occurs in those with no family history (Miller et al., 2012). In an imagining study of the brain conducted by Li et al., religion and spirituality were found to have a protective factor against reoccurrence of mental illness on those who reported that religion and/or spirituality was highly important to them (Li et al., 2018). In fact, belief in the importance of religion and spirituality was associated with thicker cortices in occipital, parietal and bilateral regions of the brain (Li et al., 2018). Therefore, neuroscience has shown that religion and spirituality may help protect high-risk individuals from going on to develop a mental illness.

## Future Research

This study will continue by conducting semi-structured interviews and surveys with a convenience sample in the Dayton area. These interviews will consist of questions such as:

> What do you believe the purpose of prayer or meditation to be?
>
> Does your religion or spirituality impact your daily life at all? If so, how?
>
> What does your scripture, holy text or other means of personal spiritual inspiration mean to you and your life?
>
> Have you ever had what you would identify as (a) 'religious experience(s)'? If so, would you be willing to share more about that?
>
> How did it affect your life?
>
> Do you ever feel as though your religious or spiritual life gives you a sense of purpose of feelings of well-being? If yes, what do you think creates that feeling?
>
> In times of sorrow or pain, what does your faith, religious or spiritual life offer you, if anything at all?

Through the results of the interviews and surveys, I hope to find how individuals from Muslim, Jewish and Christian faith communities believe that their faith, religion and spirituality impact their own mental health and well-being.

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# Resources for Music Therapists Working with Latinx Communities Within the United States

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## Abstract

Ever since its inception, music therapy has been helping clients to live more fulfilling lives. However, music therapy literature lacks information on working with diverse populations. I will focus on the discrepancy of music therapy services within the Latinx population in the United States. This literature review will establish the need for music therapy services for Latinx communities and how music therapists can respond to Latinx populations. I am writing about all Latinx communities but will focus on the efficacy of music therapy for Latinx immigrants. Additionally, I will discuss how music therapy treatment should occur for diverse clientele through the use of different methods of music therapy.

## Description

Music therapy is a health profession established to improve clients' lives and accomplish goals through music experiences. These music experiences include listening to music (receptive method), re-creating music that already exists (re-creative method), creating music on the spot (improvisation method), and to produce music that does not already exist (composition method) (Bruscia 127). Music therapy can be applied to virtually any population, such as people with special needs, physical disabilities, mental illness and more.

However, like many other healthcare professions, music therapy lacks training in diverse populations. The American Music Therapy Association (AMTA), the governing body for music therapists practicing within the United States, has a list of professional competencies that a music therapist must meet in order to be a certified music therapist. Competencies 17.9 and 17.11 under "17. Professional Role/Ethics" state, respectively, "17.9 Demonstrate knowledge of and respect for diverse cultural backgrounds" and "17.11 Demonstrate skill in working with culturally diverse populations" (AMTA). These competencies show that having knowledge of diverse populations is necessary for a music therapist. Yet, most undergraduate music therapy programs lack cultural training. It is critically important to have this training in order to produce more culturally relevant music therapy.

The Latinx population within the United States is one that could highly benefit from music therapy. As with any other ethnic group, they experience mental health issues, disabilities and issues associated with aging that could be aided through music therapy. However, music therapy is often inaccessible to these communities due to issues of socioeconomic class, income level, and knowledge of music therapy. Additionally, many music therapists do not feel that they received adequate education of

how to work with Latinx clients. In a survey done by Vandervoort in "Hispanic Populations in the Southwestern United States," 67 percent of the music therapists surveyed at least somewhat agreed that they had received some training on culturally relevant music therapy in general, but only 33 percent felt that their training related to Hispanic clients (Vandervoort 33). Latinx and Hispanic populations face unique challenges that some music therapists may not be equipped to encounter. They face issues of racism, immigration, language barriers, stigma of mental health treatment, and statistically lower educational status and socioeconomic class. Latinx communities are less likely to seek out healthcare in general because they may feel that services are culturally incompetent to their needs (Vandervoort 2). This translates into music therapy because Latinx clientele might feel uncomfortable requesting music therapy services if the therapist does not know enough about their culture or their language. Additionally, because of the current political context and feelings towards Latin American migrants within the United States, many Latinx communities may experience distrust towards white Americans. American music therapists must be aware of this in order to prevent and solve conflicts of power and race that could arise in therapy.

In order to make clients more comfortable, music therapists need to consider familial roles, broader culture, and traditional music styles and instruments when structuring sessions in order to provide the best care possible. The music therapist may also want to issue a disclaimer expressing that they in no way can speak for the client's experience and understand any distrust they may have towards them. Not every person within Latinx communities will experience their culture in the same way, so music therapists must consider the client's preferences and ask them how they would like their culture reflected in therapy. In order to try and correct the lack of literature on culturally relevant music therapy for Latinx populations, I will outline how music therapists can define and practice music therapy differently in order to meet the needs of these diverse communities.

## Labels: Latinx, Latino, or Hispanic?

In this review, I have referred to the communities I am speaking of as Latinx. The reason why I use this term as opposed to other popular labels, such as Latino and Hispanic, is because Latinx seems to be the most inclusive term for Latin American communities within the United States. Hispanic, as a noun, is a term that refers to "a Spanish-speaking person living in the U.S., especially one of Latin American descent" (Oxford English Dictionary). The problem with this term is that it does not include those of Latin American descent that may not speak Spanish. This term has more to do with language rather than culture. The term Latino, defined as "a person of Latin American origin or descent, especially a man or a boy" (Oxford English Dictionary), encapsulates the culture and geography of the community more than the definition of Hispanic does. However, in Spanish, the ends of words dictate gender: "-a" denoting a woman and "-o" denoting a man. In an effort to be more inclusive of LGTQ+ people and their experiences within the Latin American community, many have adopted the term Latinx to refer to those of Latin American origin or descent in a gender-neutral way. Since the suffix "-x" does not denote gender, the term does not assume the gender of a person and is more inclusive of all identities within the Latinx community. Because of the inclusivity of this word, I will use the term "Latinx" when describing the communities in this review.

## Comparing Definitions

A large part of my work centers around identifying how and why music therapy is not currently accessible to a majority of the Latinx population. I concluded that one of these reasons could be how we define music therapy. Because of the lack of accessibility for diverse populations within the music therapy profession, music therapists need to learn how to define music therapy in a way that pays attention to both cultural and communal themes. Considering that music therapy began in the United States and Europe, other countries and potential clients outside the Eurocentric worldview may not understand how music therapy can relate to their cultures. Definitions of music therapy vary between music therapists and international organizations. Accordingly, not all these definitions

are appropriate for specific clientele, especially for Latin American communities. As reported by the Substance Abuse and Mental Health Services Administration, 15 percent of the Latinx population in the United States had a diagnosable mental illness within the past year, which is equivalent to 8.9 million people (Substance Abuse and Mental Health Services Administration). Latinx communities do tend to face lesser rates of mental illness than non-Latinx whites but are less likely to seek and be able to afford treatment (Alegria, Table 3). Due to staggering statistics and the lack of accessibility, the need for greater mental health treatment within the Latinx population is great. Part of this treatment can and should include music therapy. However, because of the lack of a standard definition of music therapy that is culture-centered, many Latinx people do not know about music therapy. Many current definitions of the field fail to identify the needs and aspects of music therapy that may apply to Latinx communities, such as factors of community, spiritual needs, and the overall promotion of health and well-being. I am comparing three definitions from the American Music Therapy Association, World Federation of Music Therapy and Dr. Kenneth Bruscia to discover how definitions may encumber or advance knowledge and accessibility of music therapy treatment.

The American Music Therapy Association's (AMTA) definition tends to focus more on the individual rather than the community. The existing definition found on their website reads:

> Music therapy is the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program.

Music therapy is an established health profession in which music is used within a therapeutic relationship to address physical, emotional, cognitive and social needs of individuals. After assessing the strengths and needs of each client, the qualified music therapist provides the indicated treatment including creating, singing, moving to and/or listening to music. Through musical involvement in the therapeutic context, clients' abilities are strengthened and transferred to other areas of their lives. Music therapy also provides avenues for communication that can be helpful to those who find it difficult to express themselves in words. Research in music therapy supports its effectiveness in many areas such as: overall physical rehabilitation and facilitating movement, increasing people's motivation to become engaged in their treatment, providing emotional support for clients and their families, and providing an outlet for expression of feelings (AMTA).

This definition, though quite lengthy, is one of the most widely accepted definitions of music therapy in America. The question remains as to why this is the widely accepted definition. It is probably due to the fact that the AMTA is the only governing body of music therapy within the United States. With only one association to unite all music therapists, the definition that the AMTA holds are reflected in many music therapists because they receive similar training. This training is relegated by the AMTA, however, each university that has a major of music therapy may or may not follow the philosophies of the AMTA directly. How closely an institution follows the AMTA influences how its music therapists define music therapy.

This definition effectively explains that music therapy is done by a professional who has completed a music therapy program and identifies how music therapy can help to serve the various needs clients have, it does not address community needs or diverse populations. This may be attributed to the typical Western aims of therapy. Christine M. Sloss in "Cross-Cultural Music Therapy in Canada," notes that Western therapies tend to focus on autonomy, individual choice, fulfillment of individual needs, and nonconformity (Sloss 3). However, therapies outside of the United States and Western Europe tend to focus on group cohesion, harmony within a group, conformity, and spiritualism (Sloss 3). Because Latin America is still considered to be Western but differs greatly in culture and individualism from the United States, I will use Sloss's definition of Western therapies as therapies used in the United States and her definition of non-Western therapies to include those of Latin America, while recognizing the inherent issues in such designations. The Latinx communities do tend to fall within the Western spectrum geographically, but their means of healing tend to be less individualistic than those of the United States. Sloss refers to Western and non-Western, but in the context of these communities, perhaps a better term is non-Eurocentric therapies. Other terms may fall under differences in socioeconomic class, race, etc. There are many difficulties with

trying to define the types of typical cultural therapies these communities may have because of intersecting identities within a culture. However, the main difference in these treatment modalities influences how clients of music therapy experience music therapy. Because of the differences within individualism and collectivism between these cultures, therapies in the United States focus on the individual as opposed to Latin American therapies where they focus on the community and family. These differences can inform music therapists to adjust their practice to better fit the modality best suited for their client or clients.

The World Federation of Music Therapy, which serves as the primary organization for music therapists in Africa, all the Americas, Asia, Australia and Europe defines music therapy in a more communal sense and appeals to spiritual needs. Their working definition is the following:

> Music therapy is the professional use of music and its elements as an intervention in medical, educational, and everyday environments with individuals, groups, families, or communities who seek to optimize their quality of life and improve their physical, social, communicative, emotional, intellectual, and spiritual health and wellbeing. Research, practice, education, and clinical training in music therapy are based on professional standards according to cultural, social, and political contexts (WFMT).

This definition is not only more succinct but includes more information about the different environments, types of clients, and wider variety of needs than the AMTA's definition. Additionally, the lack of the word "needs" is refreshing – I like that the definition includes health and wellbeing rather than identifying needs, which can have a connation of a problem that needs to be fixed. I think that identifying music therapy as promoting wellbeing and health is better for communities like Latinx immigrants that may have a bias against therapy (Aguilar-Gaxiola vii). If music therapy is explained to a client as promoting health rather than fixing a problem, they may be more receptive to services. Additionally, spirituality is a large component of healing in Latin American cultures. In a telephone survey done with Latinx people residing in the United States, 60 percent of those surveyed prayed for healing and 69 percent considered spiritual healing very important (Reyes-Ortiz 1). The study indicated that many Latinx people turn to spiritual healing and alternative therapies rather than conventional medical care because of barriers to obtaining care, dissatisfaction with medical care, physician-patient conflicts, and a holistic view of life rather than a medical one (Reyes-Ortiz 1). Because music therapy can be considered a holistic, alternative therapy, the definition of music therapy should identify spirituality as a part of health for the Latinx population. Including spirituality within the definition may help Latinx communities to relate to music therapy and understand how it could help them and their larger communities.

The WFMT definition also differs from the AMTA's definition in that it includes "cultural, social, and political contexts." Including this phrase in the definition of music therapy is highly relevant to the Latinx population and to community music therapy because music therapy should be placed within the current cultural context. For example, the mistreatment of people seeking asylum at the border between Mexico and the United States is a problem within this current political context. Music therapy needs to respond to that problem and adjust accordingly to political contexts to maintain its ability to promote the health and wellbeing of all clients. It is imperative that the therapist considers the current political context within a client's culture when selecting music and planning music therapy sessions because political events have an impact on clients.

Cultural contexts are important because music therapists must be culturally sensitive about how they practice. It is critical that the music therapist considers the clients' culture in order to help the client best. The therapist must acknowledge that even if they know something about the client's culture, that client may not experience their culture in the same way as another from the same culture. Therefore, the music therapist must always ask the client how they would like their culture to be represented in music therapy and how their culture relates to their identity.

Social contexts are important to understand why there may be resistance to therapy. In Latinx culture, therapy is often considered something only "crazy" people experience. Latinx communities regularly display stigma of mental illness and distrust of medical professionals due to differences in culture and language (DeFrietas 7). Music therapists need to be aware of this when offering

services and learn how to explain music therapy to promote health rather than treating mental illness as "fixing a problem." Clients' attitudes towards therapy must be considered when defining music therapy.

Because of the focus on Kenneth Bruscia's definition of music therapy at the University of Dayton's music therapy curriculum, it is important to compare that definition to the AMTA's and WFMT's definition. Bruscia wrote this definition in 2014 and many music therapists who practice from a psychodynamic perspective attribute this practice to his definition. According to Bruscia, music therapy is:

> A reflexive process wherein the therapist helps the client to optimize the client's health, using various facets of music experience and the relationships formed through them as the impetus for change. As defined here, music therapy is the professional practice component of the discipline, which informs and is informed by theory and research (Bruscia 36).

Bruscia's definition of music therapy is the middle ground between the AMTA's and WFMT's definitions. Bruscia addresses the holistic perspective of optimizing the client's health, similar to the "health and wellbeing" phrase found in the WFMT's definition. As previously mentioned, addressing the whole person rather than fixing a "need" or "problem" a client may have may be a better way to facilitate music therapy for members of the Latinx communities because of the stigma of therapy (Aguilar-Gaxiola vii). However, Bruscia's definition does not mention community or spiritual health. Community is an important part for the definition of culture-centered music therapy because cultures outside of the Eurocentric United States place more of an importance on group cohesion rather than the importance of the individual. Additionally, spirituality, often a large element of Latinx culture, should be included within therapy when the client wants. Spirituality can also be a way to enhance group cohesion if the members feel spirituality is a common thread between them. Spirituality is an important part of healing within many cultures inside and outside of the United States, and even if the music therapist is not spiritual themselves, spiritual facets of therapy could be helpful for certain clientele.

Overall, the AMTA and Bruscia definitions do not cover the unique needs of Latinx communities. The World Federation of Music Therapy's definition is what may be the most appropriate definition to give to Latinx communities. It covers many facets of Latinx cultures, such as spirituality and promotion of well-being and health for the whole person. However, it may not encompass all aspects of Latinx culture, or cultures, as those may be different to each intersectional group within Latinx communities. There is not a "perfect" definition of music therapy, but each music therapist should consider their clients' cultures and communities when defining music therapy services.

Definitions matter because they inform training for music therapists and for how therapists introduce their roles and functions to potential clients. The client cannot receive the services they need if music therapy is not defined for them in a way they understand. How a music therapist defines music therapy directly impacts the client and the wider community. Misinformation or an inappropriate definition of music therapy for a certain culture could deter people in need from seeking music therapy services. It is critical that music therapists adapt their definitions of music therapy to match the needs of the client in order to give clients the tools they need to succeed in their lives.

## Stigma of Therapy and Music Therapy

As with most communities in modern society, there is a negative stigma against mental health and therapy within some Latinx communities. This stigma is strong in these communities because of the belief in *machismo*, "*la vida es dura*," and the collectivist culture many people hold. This is relevant for music therapists because they may encounter resistance from Latinx clientele. Resistance refers to a client's potential unwillingness to participate in or grow in therapy. It is critically important that music therapists are aware of the cultural differences between the Western/American view of therapy and the Latinx view because this will inform how music therapists can practice within these communities.

*Machismo* is the idea that men are responsible for and make all the decisions for their families (McKinney and Schwantes 1). The role of men in the family is viewed with greater importance than in the United States and Canada. This idea is quite stressful for men, not only because of the obvious stressors of that level of responsibility, but because of the context of immigration to America. Many male immigrants migrate in order to send money back to their families in Latin America, some whom are undocumented. Because of the inherent risks of immigrating illegally, these men find themselves under extreme stress to provide for their families and to remain in the United States. In a study by Cathy McKinney and Melody Schwantes entitled "Music Therapy with Mexican Migrant Farmworkers: A Pilot Study," she found that the farmworkers in the study experienced 30 percent more anxiety symptoms and 39 percent more depression symptoms than the census-matched average (McKinney and Schwantes 2). The clients expressed interest in preventative measures and support groups and found and interest in music therapy. However, they did experience some resistance to therapy because of the themes of *machismo* and because the music therapist in the group was female. Music therapists need to be aware of the gender roles within Latinx communities in order to combat this resistance that could exist in music therapy for both clients and therapists.

"*La vida es dura*," translating to "life is hard," is a common phrase in Latinx communities. What this phrase means for clients is that they may feel that life is difficult and they should just deal with it as it comes, leading to an unwillingness to accept help. Because of frequent political strife and discrimination that exists for multiple Latinx communities, they have become used to difficulties in life and may not want to enter therapy because they feel they should be able to cope with adversity that their wider communities have experienced. This is a concept that music therapists need to be aware of because, like the concept of *machismo*, it could cause resistance in therapy. It could also prevent clients from even considering therapy, especially music therapy since it is a lesser-known form of therapy. Because of this, music therapists need to advocate for music therapy aimed towards Latinx communities and think of ways to explain music therapy without appealing to stigma against therapy as aforementioned in the "Comparing Definitions" section.

Another barrier to people receiving therapy is the differences in culture in terms of collectivism and individualism. As states earlier, Latinx communities tend to be collectivist, meaning that they focus more on the needs of the group rather than the individual. Conversely, many communities in the United States, typically white communities, are more likely to focus on individual needs rather than group cohesion. Music therapists can adapt to this collectivist culture by offering more group therapy opportunities than individual therapy. Talking about music therapy as a group activity rather than an individual one seems to be more likely to attract Latinx communities. A lot of music therapy does occur in groups because people find that working with other people in similar situations makes them more comfortable and because they find enjoyment from making music with others.

Additionally, a musical stigma is the myth that music is universal. Most people have heard the phrase "music is the universal language," which is not true because understanding and the sound of music is different in every culture and region. According to Nomi Dave in "Music and the Myth of Universality: Sounding Human Rights and Capabilities," music can only be universal when individuals are acquainted with all forms of musical expression (Dave 4). There is so much music that exists in the world that in order to know all musical styles, one would have to devote their whole life to discovering all types of music. Obviously, most people do not do this, and so do not find music universal. There are too many languages, dialects, and cultural undertones of music for it to be a truly universal language. I find this relevant to music therapy because music therapists can get caught up sometimes in the romanization of music. We are all incredibly passionate about music and its power to change people, but we can forget to realize where music falls short. I think this is important because music therapists need to make sure not to assume that the music they use with other clients and that they learned in their undergraduate and graduate programs is appropriate for the Latinx population. Additionally, they need to be aware that simply learning a song in Spanish or a Latinx folksong is not enough because a therapist needs to understand the culture and meaning behind the music in order to properly use it in a session. If the therapist uses music without under-standing the culture, it could offend a client or push them away from music therapy. Music therapy is a newer field that needs more advocacy and awareness and so should be represented in the best

way possible with clientele of any culture by appealing to the intricacies of how a client wants their culture to be represented within music therapy.

## Creative Arts Therapies as a Container and Bridge

The main Latinx community that I want to focus on in my thesis is immigrants. I strive to describe resources for music therapists working with all Latinx populations, but a pressing matter in the United States political context is immigration. Many immigrants from Latin America experience racism and oppression, some even being kept in detention centers with horrible, unclean conditions. Music therapy can help to not only remedy the trauma these immigrants have experienced, but to aid their transition from their old country to their new country. Immigrants can experience what is referred to as a "patchwork identity" (Dieterich-Hartwell 5), meaning that they experience a conflict between their identity from their old environment and their identity in their new environment. Especially if a refugee or immigrant had to leave their home due to difficult circumstances such as violence or war, they might feel a significant amount of sadness over leaving their home but struggle with knowing how that fits into their identity in a new country. Not being able to identify a sense of self can lead to many psychological problems like anxiety and depression and causes conflict within a person's life. Creative arts therapies, which include music therapy, dance/movement therapy, art therapy, and drama therapy can help to solidify the client's sense of self. I will be focusing on the use of music therapy but will use the term of creative arts therapies, CATs, as that is how they are referred to in the article I am citing. In the article "Creative Arts Therapies as a Temporary Home for Refugees: Insights from Literature and Practice" by Rebekka Dieterich-Hartwell and Sabine C. Koch, *Figure 1* explains why CATs can work with adjusting refugees to their new environments:
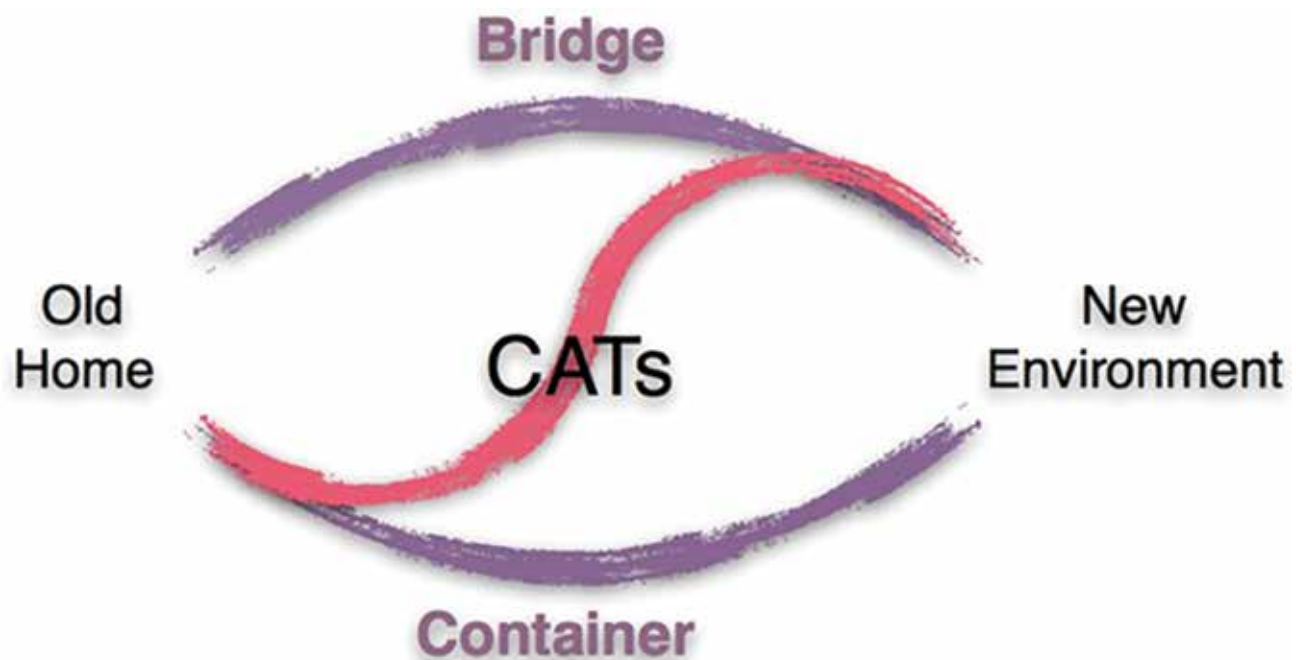


**Figure 1.** Graphic to describe how CATs can help a refugee transition from their old home to their new environment. Graphic courtesy of Rebekka Dieterich-Hartwell, 2019.

This helps to explain why CATs can work with improving the lives of refugees and immigrants because they can hold the client's culture within the music or art, acting as a container, and then acting as a bridge to the new culture (Dieterich-Hartwell 5). CATs can be thought of as a "temporary home," a safe haven where refugees can be themselves and hold their culture through music and art (Dieterich-Hartwell 4). The temporary aspect speaks to the experience of change and bridging

the old environment and new environment. An example of this through music therapy could be that the client references a song from their homeland within a session. The music therapist and client could re-create the song together. By re-creating the song in the client's new environment, they are bringing an experience from their old home into the new one. The music holds their memories of their old home, acting as the container, while the act of singing or playing the song in the new environment acts as the bridge between the old and the new.

## Community Music Therapy

Community Music Therapy (CoMT) is a model of music therapy that I find could be helpful with immigrants. A model of music therapy is defined as a "particular type of music experience used for assessment, treatment, and/or evaluation" (Bruscia 128). Models are typically thought of as how a music therapist practices and uses particular methods (re-creative, improvisation, composition, and receptive) within a session. Community music therapy can be explained as "the encouragement of musical participation and social inclusion, equitable access to resources, and collaborative efforts for health and well-being in contemporary societies" (Ansdell and Stige 600). CoMT in itself resists definition to some extent because it "encourages therapists to resist one-size-fits-all anywhere models and instead follow where the needs of clients, contexts, and music leads" (Ansdell 598). This model is useful when applied to immigrants because they have unique needs that would be difficult for any model to encompass completely. Additionally, the challenge of language barriers is present when working with immigrants and refugees. Because of this, CoMT is helpful because it focuses more on where the music leads rather than a session that is discussion-based. Since part of the definition of CoMT is to "follow where the needs of clients, contexts, and music leads," this means that a session could be done only with music because of any language barriers between the client and therapist.

An example of how CoMT can help a community is the "Scrap Metal" concert (Ansdell 600) done by music therapist Stuart Wood. This experience happened within a medical facility for people rehabilitating from brain injury. They had received music therapy throughout their treatment at the hospital but faced a big question as they ended treatment: what next? People returning to life outside of a hospital setting can be difficult and they can have trouble readjusting in the community. The music therapist enacted this concert after a client in an individual session commented, "I feel like I'm on the scrap-heap" (Ansdell 601). Other patients in the group later agreed with that statement and their project of performing a "scrap metal" concert began. Participants went to a local scrapyard and fashioned out instruments out of objects found in the scrap-yard. They then improvised on their instruments in front of others in the community, including their friends, family, and local musicians. People described it as a "transformative experience" (Ansdell 601) and felt that distinctions between the patients and wider community were removed.

This experience could be easily applied to a group of Latinx immigrants and other communities. Not only because of the language barrier, but because CoMT emphasizes equitable access to resources. Part of the reason why music therapy is not accessible to Latinx communities within the United States is because of location and income level. If music therapy was done within a communal space, such as the public concert put on by the Scrap Metal Project, it would be more widely accessible to a community. Those not participating could easily observe or the session could occur in a nontraditional location, such as a church or a community center. This would ensure that music therapy was spread to as many people as possible.

## Culture-Centered Music Therapy

Culture-Centered Music Therapy is described as "an umbrella term for description of a broad tradition within the discipline that highlights participation, action, and transactional development through music in and as culture" (Stige 538). This means that this music therapy model focuses on how music and music therapy act as culture. Culture is the way in which people experience the world. Their culture directly informs how a music therapy session should occur because culture is

indicative of life experiences. Culture-Centered Music Therapy functions on the truth that culture directs how people act in daily life and that culture needs to be considered within music therapy. A client may feel their needs are not being met if a music therapist does not consider their culture. Therefore, Culture-Centered Music Therapy is an important orientation to consider when working with Latinx communities because music therapists need to be aware of how culture can be used within sessions.

The three basic tenets of the Culture-Centered Music Therapy orientation are that culture as a resource for self and society, music as situated activity, and music therapy as health musicking (Stige 538). I will explain each of these tenets and then describe how they can be applied to Latinx communities.

Culture-Centered Music Therapy emphasizes that culture functions as a resource for the "dynamic interplay between self and society" (Stige 542). The phrase "culture as resource for self and society" means that people act and interact through use of cultural resources (Stige 542), meaning there is not a way to function in society without culture. Culture is traditionally thought of as separate from the individual. However, this thought can be problematic because it can make culture seem as a stable entity within a group level (Stige 543). This can cause overgeneralizations as to what a culture represents. Culture is perhaps the biggest influence for how people function, but a group's culture does not represent the culture of every individual. Particularly in Latinx communities, there is not one culture that applies to every person in those groups due to differences in countries of origin, citizenship status, gender, language, sexuality, etc. Culture-Centered Music Therapy helps to remedy this temptation of overgeneralization by considering culture from a resource-oriented stance. In this way, a conversation with a client from a Latinx community may focus on their personal relationship with their culture rather than what the music therapist knows of the client's culture through research. It is always important that a music therapist researches the culture of the client, but much of that research comes from asking the client themselves.

Secondly, music as situated activity is the concept that music is a verb instead of a noun (Small 9) and that music as human activity is situated because it evolves in time in a certain place (Stige 544). The notion that music is a verb means that we can consider music as an action to enable performance. Thus, the music is responsible for a performance rather than the performance being responsible for the music. Music exists in order to enable how we function with each other. This idea is a reminder of how music and context are linked in order to help music therapists consider the context of the music they may choose to use in a session. The situated nature of music suggests that music therapists take evolving events into consideration. The experience of music evolves with the evolution of the human species (phylogeny), cultural history and the development of the individual (ontogeny) (Stige 544). This understanding of music helps to inform music therapy research through the realization that the music therapists use in a session is a representation of the client's evolution of their culture, history, and development. Music therapists cannot use music with a client if they do not understand how that music has shaped culture and history. This is especially applicable to communities that have been unfairly treated and colonized by Western European nations, such as Latinx communities. Music that may seem to be neutral to a music therapist could be a reminder of oppression to a person because that music could be their oppressor's. This is way it is absolutely imperative that music therapists understand how the evolution of a culture affects how a person views a piece of music. Additionally, to relate music as situated activity and music as resource related, we can understand the relationship between history and music but can only use that music in therapy if a certain community has the resources to do so. To quote Stige, "access and active use of available resources is what matters, not the resources in themselves" (Stige 544). I have established that music therapy does not exist within many Latinx communities due to a multitude of reasons. The "music as resource" standpoint serves as a notice to music therapists that we must focus most on how to bring the resources we have to these communities.

Finally, music therapy as health musicking represents the "idea that relationships between music and health are performed in context" (Stige 545). Health musicking can be defined as "the common core of any use of music experiences to regulate emotional or relational states to promote well-being" (Bonde 121). This relates a lot to the aforementioned definition of music therapy with the

words "promote well-being". Music therapy is a health profession and establishing it as such within the Culture-Centered Music Therapy orientation can help to focus on the health of a community. This is useful within the context of Latinx communities because music therapists can focus on the health of a community. By understanding that music therapy is a health profession, community members may feel more compelled to engage in music therapy in order to take care of their health. Music therapists should advocate and promote music therapy as a way to improve health within these marginalized communities.

## Conclusion

Through examining communities that lack music therapy, we can understand how to adjust our profession to fit the needs of a group of people who are often silenced in healthcare. Music therapy is a wonderful and necessary way to aid any difficulties Latinx communities may face. In the current political context of racism and threats against the lives of immigrants in the United States, it is now more important than ever that music therapists help communities to stand against social injustice and help them to heal from whatever injustices they may have faced.

In order to be more inclusive of these communities, I have outlined how music therapists can redefine music therapy to include music therapy within a cultural context. I have explained the differences in cultures between the Western European ideas of therapy and the Latin American views of therapy. I examined how music therapy can help refugees and immigrants through detailing Creative Arts Therapies as a container of the old home and a bridge to the new home. Additionally, I have described Community Music Therapy and Culture-Centered Music Therapy, both of which music therapists can draw from when working with Latinx communities. All of the information I have complied on this subject serves to help music therapists experiencing music therapy with these communities. However, there is still work to be done.

I aim to develop this further into devising a method that will exist to better the lives of immigrants and their families within Latinx communities. Music exists as a response to social change and music therapists can help to change how these communities view themselves as well as how the wider world sees them. These resources are a start to what I hope becomes a dynamic project to enact social change for a community that has faced injustice.

## Acknowledgements

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# The Multi-Sensory Design of a Synesthete's Everyday Experience

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## Abstract

Perception—defined as becoming aware of occurrences in the world through the senses — is different for every person (Merriam-Webster 2019). The Berry Summer Thesis Institute has jump-started my thesis which deals with perception in the form of a condition called synesthesia and the communication of this condition through the medium of graphic design. Synesthesia is a condition that involves the involuntary crossing of the senses, resulting in multi-sensory experiences every time a synesthete absorbs the world and specifically, visible language. Through the visible language of graphic design, I have created several projects that communicated my three goals for my thesis, which include conducting research on synesthesia, sharing what I experience every day, and educating others about synesthesia. I have also continued to explore the English language and how certain phrases can be compared to a synesthete's everyday experience with phrases such as 'white noise' or 'feeling blue,' (Kinsler 2018). The results came in the form of several graphic design-centered projects that developed from researching exhibitions featuring synesthesia and exploration of the senses. The projects include a storybook of discovery, research posters, and a visual song. They all utilize my visual perception of the world as a synesthete through transparency overlays with my colored letters on the text of the storybook and posters, or the song that is drawn how I see it in my mind's eye. All of these elements have helped me begin my journey to educating others about synesthesia through researching the condition more in-depth and sharing my experience as someone with synesthesia.

## Introduction

Have you ever wondered the reason certain people feel the need to associate specific subjects, songs, or even people with a color? Or questioned the possible meanings for phrases such as 'white noise' and others associated with color and texture (Kinsler, 2018)? Well, there is a psychological reason for these curious connections. It comes from a neurological condition called synesthesia, which involves the involuntary crossing of the senses that affects a small percentage of the population. This condition occurs when a certain gene does not snip the connections between the different areas of the brain during childhood. The results are a multi-sensory experience every time a synesthete absorbs the world through all of their senses.

I myself am a synesthete and I consider it a gift. In my childhood years the condition led to many struggles and learning difficulties in school because of my lack of awareness. The summer between my 7th grade and 8th grade year, my mother's friend, who happened to be a reading specialist, gave

me a list of books to assist with my reading ability, interest and comprehension. I chose a book by Wendy Mass called *A Mango Shaped Space* that changed the course of my life. I was reading before bed one night and I read a part in which the main character of the book, a girl about my age at the time, was explaining what colors her numbers and letters were. I remember being so amazed that she had several different colored letters and numbers than I did. I ran downstairs with great excitement "Mom! What color is your 'a'?" to which I received a confused, concerned and surprised look from my mom. She asked, "What do you mean?" I explained that the character in the book I was reading associated different colors to her letters and numbers than I did. I wanted to know what colors other people saw too. Although, when I asked my mom, she explained that she did not see any colors with her letters and numbers. This led to my mom and I conducting a great deal of research and we determined that I had a condition called 'synesthesia'.

Using the "Synesthesia Test" online, we were able to determine that I have several types of synesthesia, including; grapheme, where letters and numbers each have their own color and texture associated with them; chromesthesia, where all sounds that I hear have colors, shapes and textures; smell to color, in which scents have a color, shape and texture; temperature to color, in which each temperature that I feel has a distinct color and/or shape; pain to color, in which different pains and feelings I experience have a color and shape associated with them; taste to color, where only some different tastes have a color linked with them; and a spatial form of synesthesia, where I am more easily able to visualize spaces and objects (Dean 2014; "Home: Auditory-Tactile Synesthesia" 2017).

Additionally, there are two different types of synesthetes when referring to the grapheme type; associators and projectors. Associators "report experiencing their photisms 'in the mind's eye'", while projectors bring the color or experience into "external space" and use the spatial part of the brain to do so (Dixon 2004). With my grapheme synesthesia I am a 'projector,' which means I project all of my colors and textures on top of each letter and number I see. I use the spatial part of my brain much more than other synesthetes. Approximately 90 percent of synesthetes are associators, making the chance of being a projector much less likely (Dixon 2004).

Looking back at various experiences and struggles I had as a child, I recognize how my synesthesia affected my learning. Despite the difficulties that I have had with synesthesia, I consider it a gift and it makes my life significantly more color rich than most. This is one of the reasons I wanted to participate in the Berry Summer Thesis Institute, because it would provide the means to deepen my understanding of synesthesia as well as an avenue to visually represent my experience as a synesthete to educate others. I am now more aware of how I process information and learn, which has helped me utilize my gift of synesthesia to help me flourish in school, life, and in a creative capacity as a graphic designer. This is an awareness that I would like to give to others and have been able to through the Berry Summer Thesis Institute.

## Background Research

When beginning the process of my thesis, I did a great deal of research in order to more fully understand the condition of synesthesia, including its scientific background, causes, and other types of synesthesia. I began by gathering numerous resources, as well as, meeting with Dr. Susan Davis. This helped me understand more deeply about synesthesia and how the University of Dayton's professors have explored the subject.

Two very important researchers in the field of neuroscience and synesthesia are Richard E. Cytowic and David M. Eagleman. Two of their books, *Synesthesia* and *Wednesday is Indigo Blue*, offered me considerable assistance in understanding how synesthesia develops in children based on how these connections between centers of the brain are made. I also learned there are many more types of synesthesia than I had previously thought.

The field of synesthesia has not been extensively studied. Recently, however, there has been an influx of books and studies published that explore the subject as well as the causes, different types, and experiences of synesthetes. During the Berry Summer Thesis Institute, I was able to read many

different sources by neurologists and artists that explore synesthesia in people with the condition as well as how synesthesia is present in everyone through our language and how connected our senses really are.

At its core, synesthesia is a condition that involves connections between the senses and perception. When a synesthete experiences one sense, or 'trigger', another sense or experience is activated as a result (Cytowic 2018, 3). Richard E. Cytowic, who is a neurologist and one of the founding members of the field of synesthesia, defines the condition as "a triggering stimulus [evoking] the automatic, involuntary, affect laden, and conscious perception of a sensory or conceptual property that differs from the trigger" (Cytowic 2018, 3). This can come in many different forms, such as grapheme-to-color in which letters and numbers each evoke a color. There are around forty different types of synesthesia that have been found, which contain both a trigger and the stimulus or experience that have been evoked (Eagleman 2009, 24).

Synesthetes often are not aware that they have synesthesia because they assume that everyone else sees the world in the same way as they do. As a synesthete, I myself was unaware until I read *A Mango Shaped Space*. If synesthetes do discover they have the condition, it is often not until much later in their life.

Synesthesia is genetically inherited and is a function of nature. In addition, it requires nurturing because the connections that are essential to the condition are formed during childhood and then remain constant throughout life (Eagleman 2009, 6, 215). Synesthesia is most likely transferred via the X-chromosome as it is more common that women have synesthesia. The gene that causes synesthesia essentially confers increased cross talk between the different parts of the brain (Eagleman 2009, 6). So therefore, if the gene is not sustained when the synesthete is a child, then they will no longer have the condition. If the condition is sustained, then the area of the brain that is triggered as a result of grapheme-to-color synesthesia is called the V4 (Eagleman, 6). This is the part of the brain that is vital for recognizing the 'color' of the trigger, which can come in the form of letters and numbers (Eagleman 2009, 6). Synesthesia is also more common in children than in adults because it is possible that children lose their synesthesia during puberty. The brains of young people are constantly changing and reorganizing themselves, which can cause synesthesia to fade. Specifically, the concentration of hormones during puberty can cause young synesthetes to lose their gift, even as young as the age of six or seven. If the condition of synesthesia lasts past puberty, then it will stay for the remainder of their lives.

The number of people with synesthesia has changed constantly throughout the ages due to studies that have been conducted. It is also difficult to estimate the amount synesthetes due to the fact that people with the condition are sometimes not aware that they have it. The most recent statistics include one in twenty-three for any type of synesthesia and one in ninety for grapheme-to-color, which is the second most common form of synesthesia (Eagleman 2009, 7).

Synesthesia is a growing field that has sparked continued research studies and publications in an effort to educate others. This has also helped remove misconceptions about the condition, such as that synesthesia is too strange or "New Age" that it should not be studied because it is not a respectable field (Eagleman, 4). This has helped synesthetes understand that what they experience is not strange but that there is a reason for it. I look forward to continuing my research and sharing it with others in order to educate them and increase the amount of people that are aware and knowledgeable about synesthesia.

## Goals

From the conception of my thesis, I developed three specific goals that have and will keep my thesis on track in order to optimize the impact of my thesis as an educational tool. My goals include; conducting research on the condition of synesthesia, as well as causes, types, and the overall logistics; sharing my experience as a synesthete through various means that engage multiple senses and give people a sense of what I experience; and finally educating others about the condition through graphic design-centered projects that engage my previous two goals.

## Design Plan

The medium of graphic design provides me the opportunity to communicate the message of synesthesia to others interested in the condition as well as others with the condition. I first began by brainstorming how I could visually represent, through the medium of graphic design, synesthesia. I developed the idea of completing a book that would help tell my story of discovery that would hopefully prompt the discovery of others' synesthesia. I also wanted to communicate the research that I have done on synesthesia to educate other synesthetes and those desiring to learn more about synesthesia. Furthermore, I had been working on drawing the colors and shapes I see when I experience sounds, smells, temperatures, pains, and some tastes. Therefore, I thought that the avenue that would be most effective when combining all of these experiences would be visually creating a song.

Based on my previous goals that I developed to direct my thesis and the brainstorming that I had done, I established a graphic design-centered action plan to carry out these goals. This action plan included three separate parts. Those parts first included a storybook of discovery, in which I would photograph, design, and make a storybook telling the story of when I discovered I had synesthesia to educate others about the condition and help with their own discovery. Second, I would design posters that would be centered around the research that was most valuable to educate people about more of the logistics of synesthesia using photographs that I took of the books. For the third part, I planned to create a song using Adobe Illustrator to convey to others how I visually experience sounds and music. With this starting point that I created based on my goals, I would be able to use graphic design in order to communicate the important message of synesthesia.

## Products

Over the summer, I have completed the storybook of discovery, three research posters and part of the visual song. Below are the descriptions and photographs of each of the design projects.

The first element that I described, The Story of Discovery, was fully designed and created for the Berry Summer Thesis Institute Symposium. The story begins when I was between 7th and 8th grade. I struggled a great deal with reading because it took me a long time to comprehend, which would sometimes result in re-reading parts of books and articles over and over again. My mom's friend, who is a reading specialist, recommended some books for reading over the summer. This story begins when I started to read *A Mango Shaped Space*.

Following are photographs of the final printed version of the Storybook of Discovery as well as some of the inside spreads. Over the top of all of the right spreads is transparency paper, which contain my colors in order to help give people the experience of a synesthete.

**Figures 1 and 2.** Final printed version of the *Storybook of Discovery*. Photographs courtesy of Madeline Spicer, 2019.



**Figure 3.** Interior, final printed version of the *Storybook of Discovery*. Photograph courtesy of Madeline Spicer, 2019.
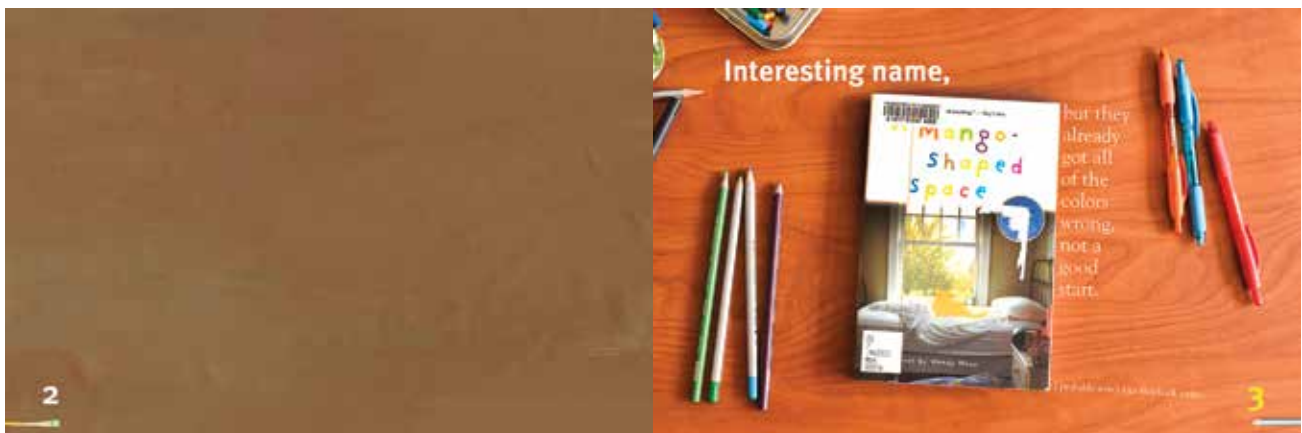


**Figures 4 and 5.** Interior pages, *Storybook of Discovery*. Designs and photographs courtesy of Madeline Spicer, 2019.
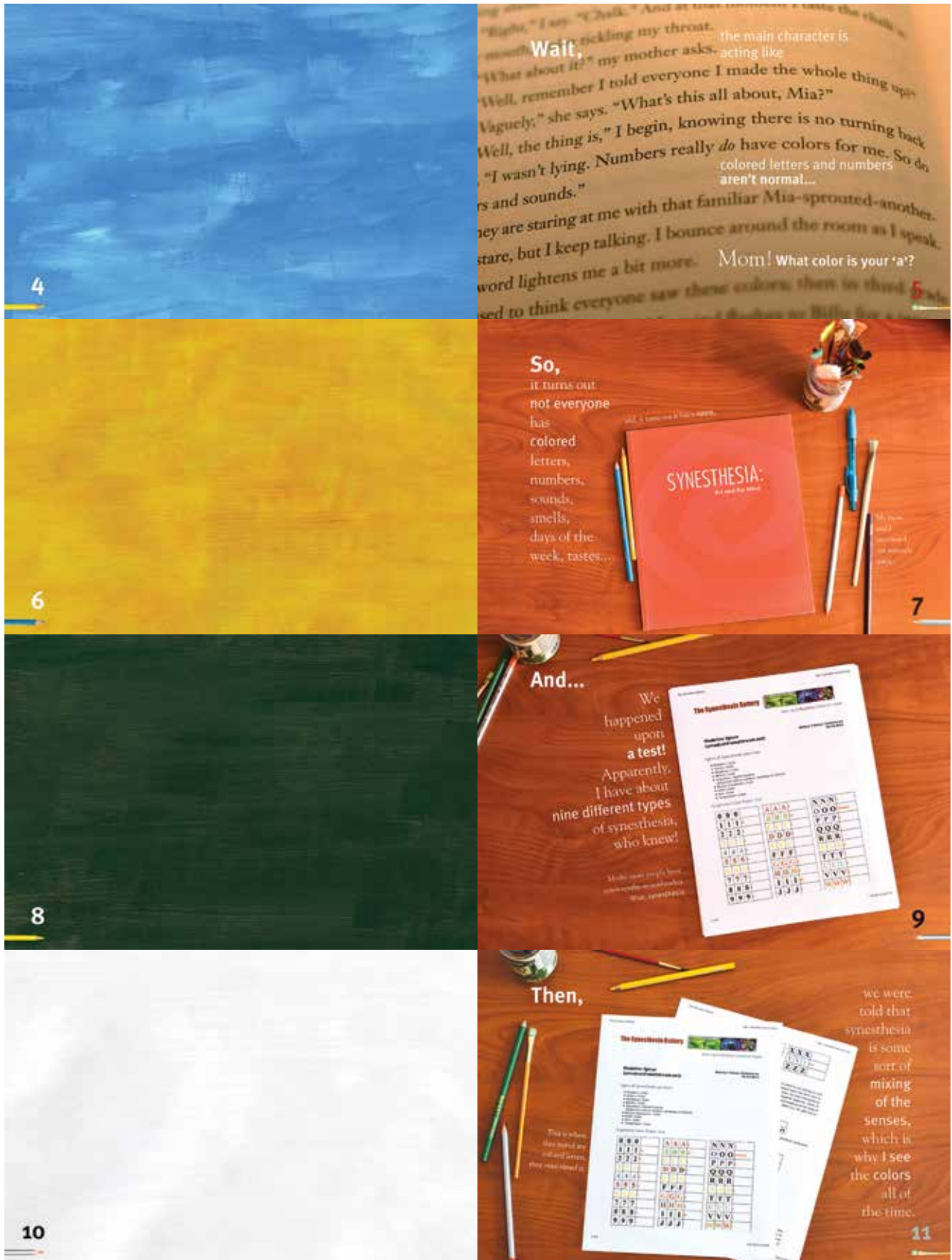
**Figures 6 through 13.** Interior pages, *Storybook of Discovery*. Designs and photographs courtesy of Madeline Spicer, 2019.

**Figures 14 through 21.** Interior pages, *Storybook of Discovery*. Designs and photographs courtesy of Madeline Spicer, 2019.

**Figures 22 through 27.** Interior pages, *Storybook of Discovery*. Designs and photographs courtesy of Madeline Spicer, 2019.

Following are some additional designed spreads of the storybook, where the text is on the right side and the facing page on the left is the color of the page number.

The second part of my design plan was research posters. I used a similar design as my book to create the posters, which included a photograph of the book that I found particularly helpful. I then surrounded the pictures with information about synesthesia or the senses that are helpful to understanding the condition and how our senses are more connected than people might believe. I then overlaid my colored letters and numbers using transparency paper to visually represent what I see in order for others to understand.
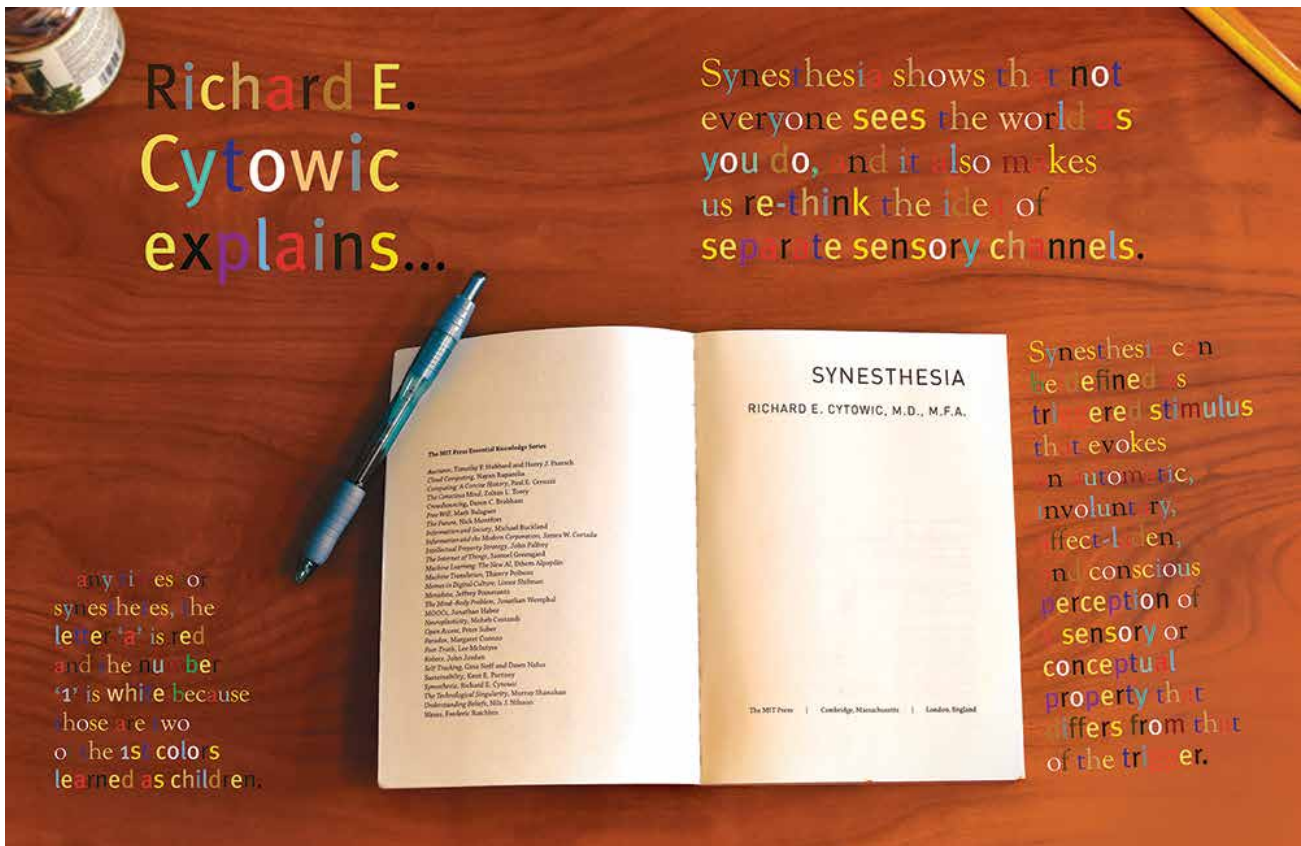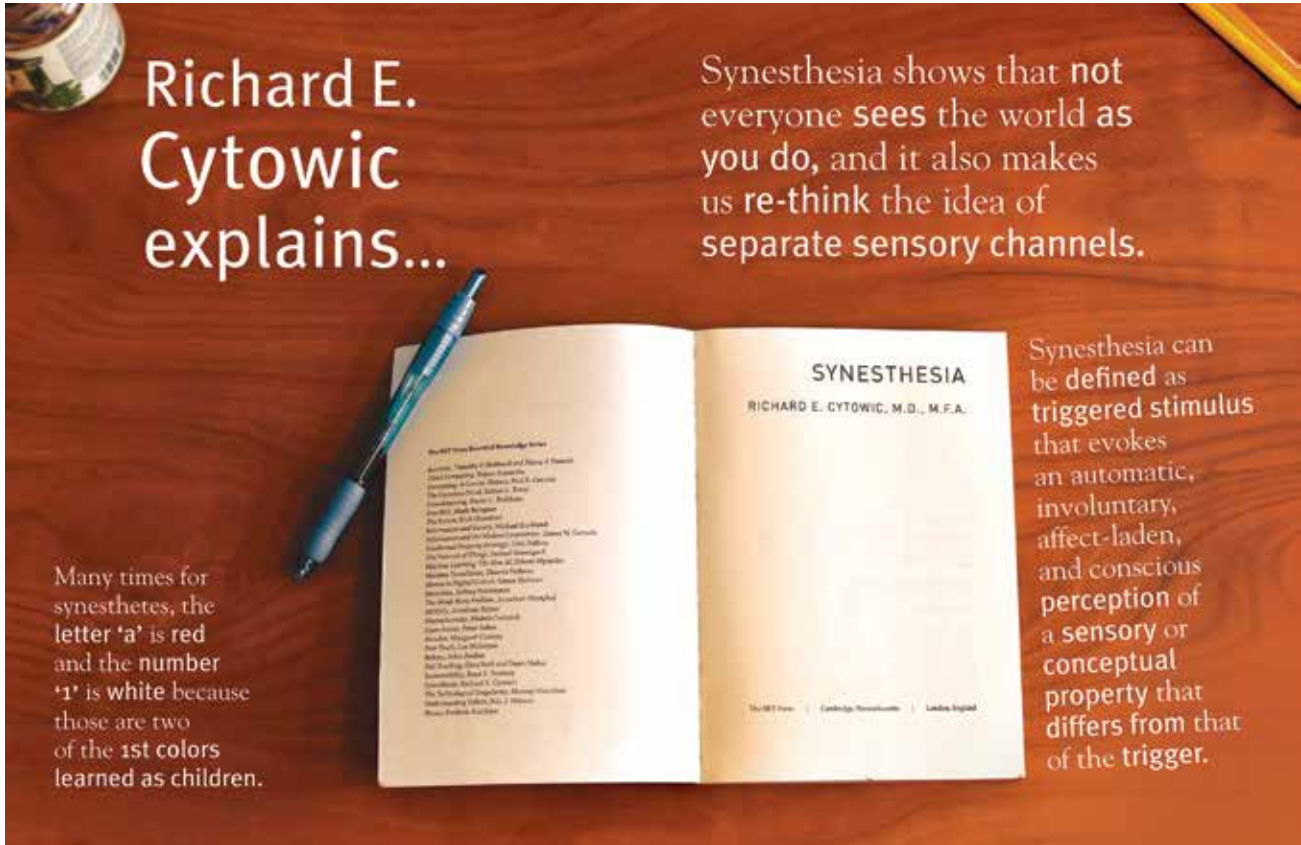
**Figures 28 and 29.** Posters. Designs and photographs courtesy of Madeline Spicer, 2019.

**Figures 29 through 33.** Posters. Designs and photographs courtesy of Madeline Spicer, 2019.

Finally, for the visual song I am creating, I have chosen the song "It's Time" by the band Imagine Dragons. I have chosen this song because it is the first song that I drew for my mom when I discovered that I had synesthesia. Over this summer, I have begun designing how the song looks in my mind's eye using Adobe Illustrator. Below are some of the first slides that I have created. Each slide represents five seconds of the song and will be played similar to a slide show timed with the music.



**Figures 34 through 39.** *It's Time* song illustration. Designs courtesy of Madeline Spicer, 2019.

## Future Design Plans

During my junior and senior year, I plan to continue the work that I have started during the Berry Summer Thesis Institute by refining my Storybook of Discovery, designing and creating more research posters, and finishing my visual song. Using this summer as a strong starting point, I am a more informed synesthete and designer and have had the time and resources to create prototypes that will help me move forward in a productive direction. In the future, I hope to use the knowledge and skills that I have gained over the summer to educate the community about synesthesia using my thesis designs.

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# Sustainable Stories: Linking Graphic Design and the Environment to Inform, Educate and Inspire

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## Abstract

Graphic Designers have the ability and the responsibility to visually communicate messages to an audience and it is my belief that sustainability is a message which urgently needs to be communicated. The salient nature of the topic of sustainability makes it applicable to audiences both young and old, gives it the versatility to cross and connect disciplines, and further emphasizes the importance that action be taken quickly and collectively to ensure the preservation of our planet. As the fields of design and sustainability have continued to grow, the potential for creative solutions has also expanded — offering opportunities for linking the disciplines to each other and providing hope for a better world. As designers and authors Eric Benson and Yvette Perullo note: "It's not about doing less bad, it's not about achieving a net zero impact, but it's about actually making the world a better place."[1] Design is an avenue for effecting this type of identifiable, lasting change.

## Sustainability

Defining what is meant by the term sustainability proves no simple task as it is influenced by a variety of factors such as cultural, environmental, social, economic, etc. backgrounds that may shift depending on which individual you ask and at what time. A report published in 1987 by the Brundtland Commission entitled *Our Common Future* defined sustainability as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[2] In this way, sustainability can be thought of as thinking about the future, or, as authors of *Cradle to Cradle: Remaking the Way We Make Things* William McDonough and Michael Braungart describe, it's questioning — "how can one design or manufacture in a way that loves all children, of all species, for all time?"[3] These definitions illustrate that sustainability encompasses more than environmental conscientiousness. There are three pillars which must be functioning together in order for sustainability to be achieved: the environmental, the economic and the social. Each pillar plays a role in maintaining the balance between the complex web of systems that make up our world. My research has communicated to me the integral importance of these interconnections and further emphasizes the impact that even individual actions can have on the sustainability of the whole system (our Earth).

As I learn more about sustainability, I must also reflect on how my work as a designer fits into a sustainable future. The design industry can be incredibly wasteful; designers print on a lot of paper, contribute to the multitudes of packaging waste that can be found in our landfills, and are

responsible, in part, for the vast quantities of carbon entering our atmosphere. Benson and Perullo's book, *Design to Renourish: Sustainable Graphic Design in Practice*, further acknowledges that, "Graphic Designers are complicit in an industry that creates literal mountains of waste, contributes to the destruction of natural habitats, and poisons waterways and the atmosphere."[1] Despite this, as Benson and Perullo similarly express, Graphic Design is an immensely powerful tool for disseminating information and inspiring change. More and more designers have been developing ways to be environmentally aware — selecting sustainable materials and thinking more creatively about how to address clients' design needs. These designers are willing to put forth the extra effort required to implement a sustainable design practice and are cognizant of the ways that their work effects the world around them. In his book, *A Sand County Almanac, and Sketches Here and There*, naturalist and writer Aldo Leopold states that "a conservationist is one who is humbly aware that with each stroke he is writing his signature on the face of his land."[4] My research has taught me that designers, and indeed all people, must learn to think in this way as well.

## Inspirations

In deciding what form my thesis project would take, I thought about what first inspired my own passion and commitment to sustainability and the environment. I found my answer in the pages of a children's book and the image of a watercolor manatee named Ana Lee. I read Rich Bray's book, *Ana Lee the Manatee*, at the age of six and have loved the manatee and its underwater world ever since.[5] Julia Matteson's watercolor illustrations captivated my imagination and sparked my desire to protect the creatures of the planet so that future generations could fall in love with the manatee the same way that I had. After having experienced first-hand the way that a children's book could inspire a lifetime of dedication to a specific cause, I knew that I wanted to pursue writing and illustrating my own children's book. This book would serve to help deepen my understanding of both sustainability and design, would provide me the ability to discover more about the ways that the two disciplines overlap, and would contribute to the growing conversation about the necessity of connecting children to nature.

## Gathering Information

In preparation for writing, illustrating, and designing my own book, I collected and read a variety of books which covered topics including sustainable graphic design, environmental art and environmental education. The books built on my foundational knowledge of design and sustainability and further inspired the direction of my book. In addition, I also gathered a selection of children's books focusing on nature and environmental themes to get a sense of how the authors illustrated and constructed an interesting, informative narrative. The following is a selection of some of the books from my research that I found to be most useful in shaping my own sustainable story.

### *Design to Renourish: Sustainable Graphic Design in Practice*[1]

Benson and Perullo's book aimed to serve as a case study for how to produce a completely sustainable book. Unfortunately, they experienced challenges which prevented them from being able to accomplish their aim. Their experience evidences the difficulties that arise when trying to design and print sustainably. Their failure does not suggest, however, that sustainable design *can't* or *shouldn't* be done. Rather, they describe how their own experience demonstrates exactly why design should be striving for better. The rest of the book provides examples of studios and projects which pursue sustainable methods and materials in the creation of their designs. The themes directly correlate with my own aim of producing a sustainably conscious book and also with my aspiration of establishing a sustainable design practice in my future career. The book illustrates that there is still a lot of room for improvement, but also provides me with the inspiration that there are people just as willing as I am to try.

## Cradle to Cradle: Remaking the Way We Make Things[3]

As an architect and chemist, McDonough and Braungart describe their experiences with our climate situation and provide highly innovative potential solutions to the problem. The book challenges even what most environmentalists and bio-conscious people consider to be at least steps in the right direction, saying that simply being "less bad" is not good enough.[3] Keeping this concept in mind, the authors describe how their book is printed on paper made out of recycled plastic using a method called DuraBook technology. McDonough and Braungart's insights got me thinking about the materiality of my own book and challenged me to pursue sustainable alternatives to the materials I chose.

## The Failure of Environmental Education (And How We Can Fix It)[6]

Saylan and Blumstein's book focused on the shortcomings of the environmental education system and also provided suggestions for how to improve upon it. They state that "students and indeed all citizens, need the capacity to see intangible value in things: forests simply for the sake of forest; the expanse of wilderness simply because it is alive, primal, and fiercely beautiful."[6] Some of the points they made which I felt to be most significant included the need to bring children out into nature (preventing the current trend of "nature deficit disorder" — a term coined by Richard Louv[7]), being willing to employ creative solutions, encouraging imagination, and taking on individual responsibilities for the climate situation. In writing my book, I aimed to incorporate some of these possible solutions discussed by Saylan and Blumstein in the hopes of creating a more aware and engaged society, starting with its youngest members.

## Art & Ecology Now[8]

Brown's book provided me with examples of artists who engage with the environment through their art. Some use environmental materials, some employ environmental themes and some encourage protection of the environment. Each artist that he describes has their own unique and specific manner of creating and engaging with the material. This resource was beneficial in exposing me to research which examines the overlap between art and ecology — something that I hoped to achieve through the production of my children's book.

## A Sand County Almanac, and Sketches Here and There[4]

Aldo Leopold's book is beloved by naturalists and conservationists for its poetic and powerful language calling on its readers to reconnect with the land. Leopold's "land ethic" explains "that land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics,"; he follows up this concept with the idea that "we can only be ethical in relation to something we can see, understand, feel, or otherwise have faith in."[4] In this way, he demonstrates that ethics are connected to awareness — it is difficult to care for something that you have never heard of before. Many people are losing the ability to recognize that all things inherently have value, beyond that of the economic. These ideas became core components of my children's book, inspiring me to engender interaction and to help readers build meaningful relationships with their own natural world.

## The Lost Words: A Spell Book[9]

A similarly inspiring and influential book entitled *The Lost Words: A Spell Book* written by Robert MacFarlane and illustrated by Jackie Morris, is a children's book which details and describes 50 words "lost" from the Oxford Junior Dictionary. The book opens, "the words were those that children used to name the natural world around them: acorn, adder, bluebell, bramble, conker — gone…no

longer vivid in children's voices, no longer alive in their stories."[9] Information provided on the back of the book further explains that these lost words were replaced by technological ones such as blog and email — words which were apparently frequenting children's speech more often than the nature words. I was shocked to learn that words like dandelion and acorn which ranked high on my own childhood linguistic-descriptor list were being outpaced by children's use of words like chatroom and attachment. I could not fathom a child looking at a dandelion and not knowing or caring what it was called. After reading Macfarlane's book I had a strong sense of the narrative that I wanted to communicate to children — using naming as a means to reconnect children to outdoor experiences.

## Process and Exploration

### MATERIALS RESEARCH

In developing my thesis project, it was important to me that I made an effort to realize a thesis in which content and context were consistent with the ideals of sustainability — necessitating further research on the materials that I would use and the final form that my project would take. This graph indicates how much paper I have used as a Graphic Design major since beginning my education at the University of Dayton. There are statistics which also describe the organizational environmental impact of the Art and Design Department at the University of Dayton including tree and energy consumption, as well as, carbon emission.

After having seen the environmental impact of printing on paper, I explored the possibility of implementing the same DuraBook recycled plastic technology that McDonough and Braungart utilized to produce *Cradle to Cradle* for my own book. However, I decided that finding a 100 percent recycled paper source was the most feasible, sustainable design decision for my summer work. The
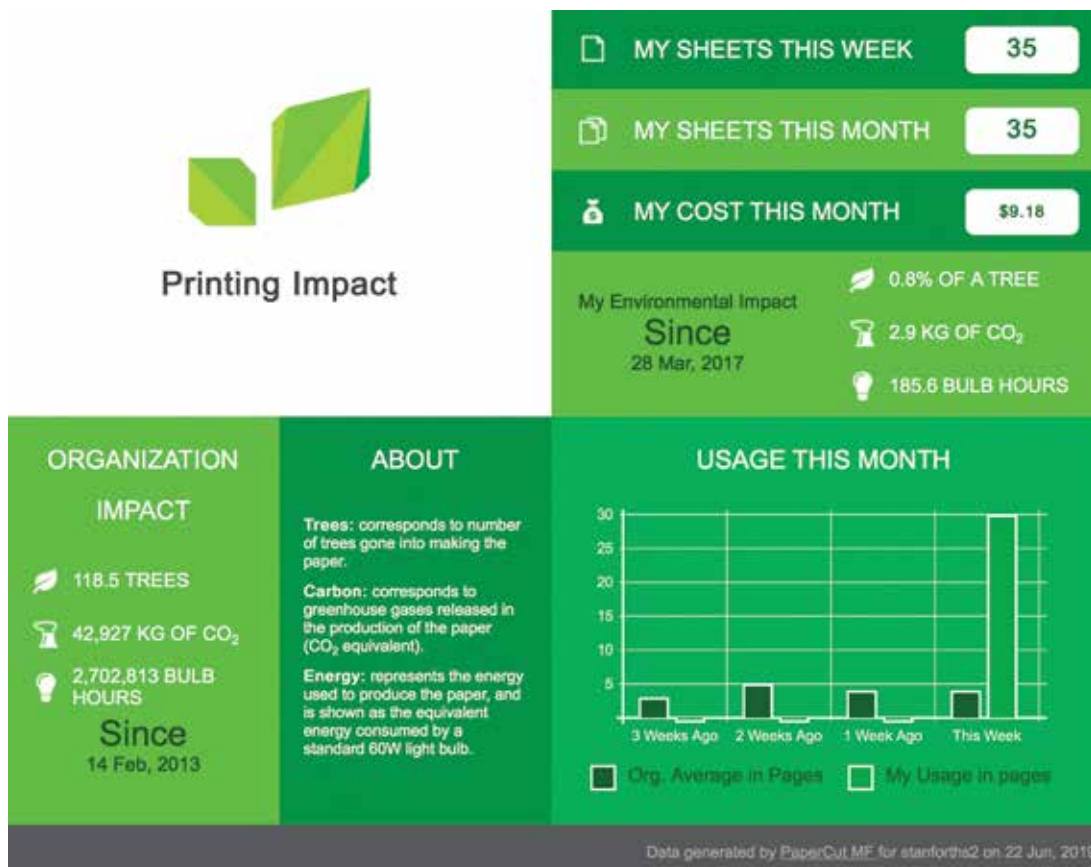


**Figure 1.** Data retrieved by Shannon Stanforth, 2019.

paper that I selected for my book is 100 percent post-consumer recycled paper from the Neenah Environment® collection which meets the FSC® standard for responsible forestry and is produced without the use of chlorine. I also had to ensure that the paper size I ordered aligned with the dimensions that I had decided for my book so that there would be little excess paper after production. As I continue my thesis research, gaining more information on how to print and produce a book sustainably with ethically and environmentally sourced materials will remain an ever-present, ever-evolving component of my project and design process.

## ILLUSTRATIONS

I also explored and experimented with ways to sustainably craft my illustrations. Ultimately, my book includes a mixed media illustration approach which incorporates images produced with acrylic paint, colored pencil, and repurposed magazine scraps. Some of the critters and creatures featured in the book are composed of layered hole punches from magazine pages. I wanted to emphasize the magazine details in order to display one way that creativity and sustainability can be linked to provide an alternative design solution.

## WRITING PROCESS

Knowing that I wanted naming to be a central theme of my book, I used the Oxford English Dictionary as a resource to research the etymology of specific species and beings. Discovering their origin allowed me to place their historical significance, connect them to their surroundings and make them more meaningful to young readers. Furthermore, through reading a number of children's books as part of my preparatory research, I knew that the books that rhymed were the ones whose message resonated the most with me. Therefore, I decided to develop a rhyme scheme to be followed as an organizational structure for the book. I composed a five-line stanza which used the scheme A, B, C, C, B. For example:

A   Thank you! Now, I feel much better

B   And you will hear a tale from me

C   It all begins in circa 825

C   That's when my ancestors were all alive

B   And people first started calling them — trees!

In this example, "better" stands on its own, "me" rhymes with "trees", and "five" rhymes with "alive". This rhyme scheme aided me in writing the rest of the book and provided the linguistic foundation for my writing process.

## DESIGN DECISIONS

The design process included the arrangement of spreads, text and illustrations. Additionally, one of the most important design decisions that I needed to make was which typeface would serve as the primary and accent face for the text of the book. A typeface refers to the shared style, structure and form of a specific set of letters. I researched and explored typefaces, analyzing them based on criteria such as their sustainability and legibility. Ryman Eco, an environmentally sustainable typeface designed by Dan Rhatigan with Grey London, was selected for the main text of the book. Launched in 2014, the typeface is considered sustainable because it uses 33 percent less ink in production, cutting down on the amount of material necessary to print the text. I chose the Shannon typeface as the accent for my book for its legibility and readability. Shannon was designed by Janice Prescott Fishman and Kris Holmes for Compugraphic in 1982.

### THEY NAMED ME, THEY KNOW ME

I titled my book, *They Named Me, They Know Me*, in reference to the relationship created between one individual and another through the use of a name. Naming serves as the first step in building awareness, which eventually leads to respecting and caring. The following is a selection of spreads from *They Named Me, They Know Me* which is told from the point of view of a tree who has become the pages of the book. The tree begins its tale asking for the reader's participation and interaction, continuing its story by naming the flowers, the butterflies, the birds, the frogs and the fish. The trees cheery tone is darkened when the people forget the creatures' names, but is brightened by the hope of remembrance.

I'd like to tell you a story,
But I can't do it in here.

You see, it's much
Too dark
For a tree that used
To have bark
To be **inside**
When the **outside**
Is so near.

You'll need to find me a sunbeam.
Please, open me up to a band of light.
After I'm warmed by a golden ray,
Then I can **reveal** what I'd like to say

In **words** that
Only a once-wise
Tree can write.
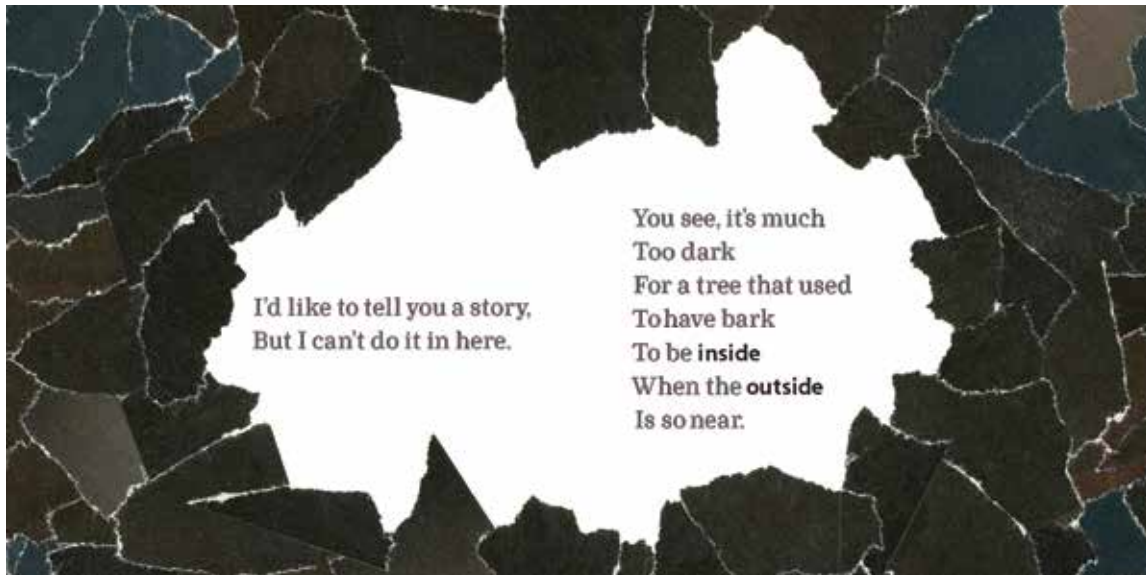
Will you find me a flower please?

**Quick!** Plant one in my pages,
Place its petals on my letters,

And then I will remember
How the **flowers** got their
Names throughout the ages.

**Wait!**

Be sure to find a fallen flower.
Don't pluck it from the ground
Or from the branches of a tree.
That way **others** can still see the
Beauty of the flower you found.
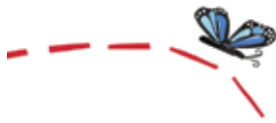
100 years later butterflies were named.
Floating and flying through the sky
Their fluttering **wings** and bright colors
Set them apart from one another.

How **many** butterflies can you spy?

As I am sure you are starting
To see, every **creature** has a name.
And the more we know,
The easier it is to show
That caring for them is our aim.

All the creatures knew
That the people **cared** for them
Enough to give them a name.

But then something **terrible** happened...
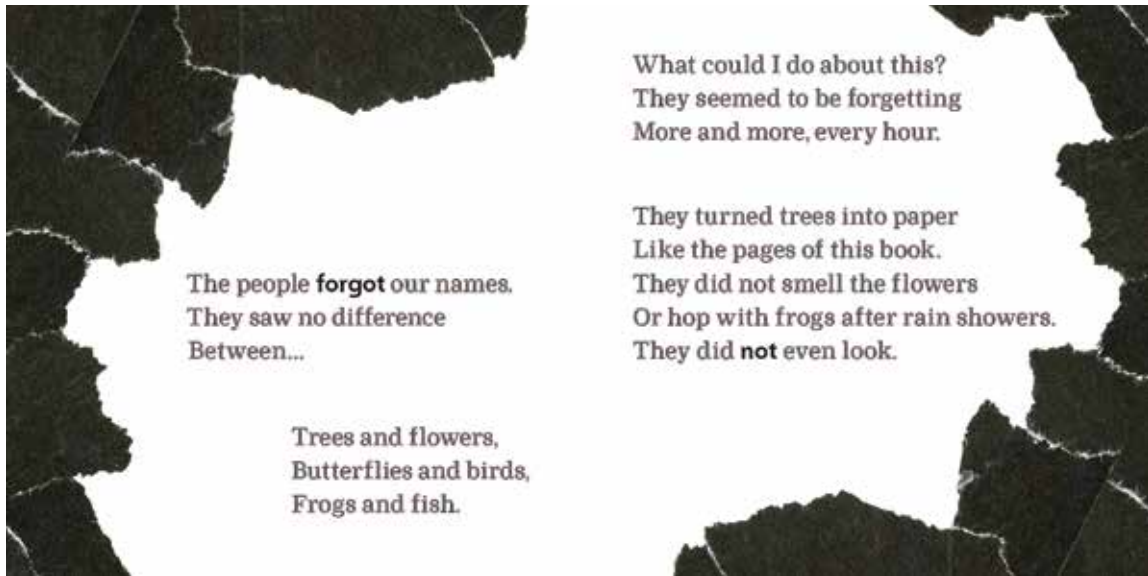
The people **forgot** our names.
They saw no difference
Between...

Trees and flowers,
Butterflies and birds,
Frogs and fish.

What could I do about this?
They seemed to be forgetting
More and more, every hour.

They turned trees into paper
Like the pages of this book.
They did not smell the flowers
Or hop with frogs after rain showers.
They did **not** even look.
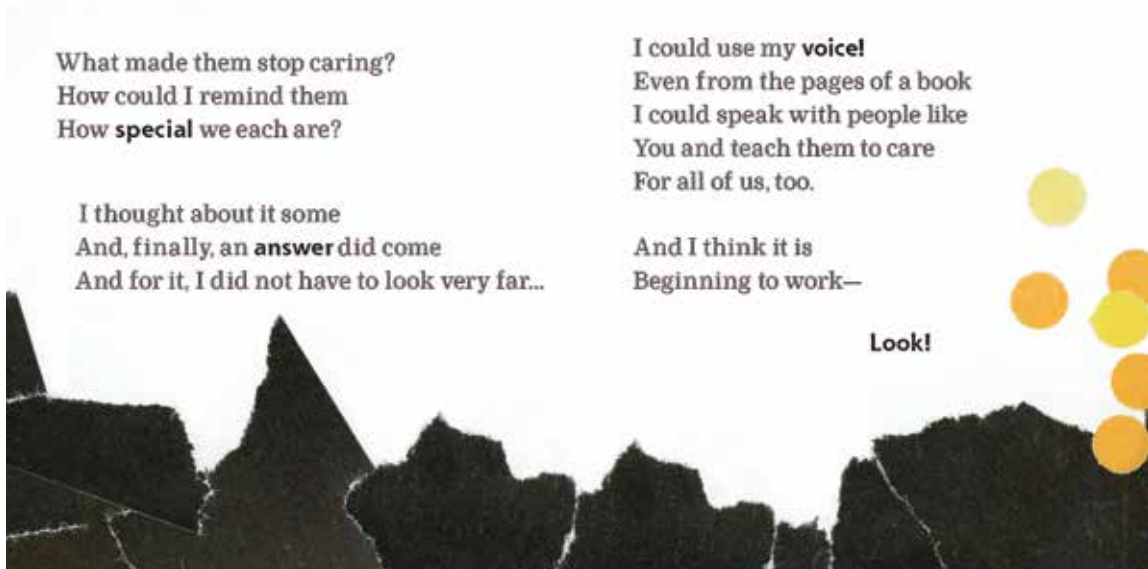
What made them stop caring?
How could I remind them
How **special** we each are?

I thought about it some
And, finally, an **answer** did come
And for it, I did not have to look very far...

I could use my **voice!**
Even from the pages of a book
I could speak with people like
You and teach them to care
For all of us, too.

And I think it is
Beginning to work—

**Look!**

This is the end of my tale.
So, now that you know us
Please don't forget our names.
Because **you** and **we** are
One in the **same.**

Help others
To **remember—**
You have my trust!

**Figures 2 through 17.** *They Named Me, They Know Me*. Designs and Photographs courtesy of Shannon Stanforth, 2019.

## Book Making

The book is done in the accordion format as I felt this was the most playful and interactive form for a children's book. It encourages the child to pick up the object, to read it, to take it outside and to connect with its message. As I continue my research, I hope to improve upon the durability of the accordion book so that it may better serve its interactive purpose.



**Figure 18.** Photograph courtesy of Shannon Stanforth, 2019.

## Future Studies

Moving forward, I plan to research more about the publishing process for children's books; Deepening my understanding of printing and publishing will be a vital component to producing a sustainable book. Reaching out to others who have experience in the field will be one of my first steps as I continue to pursue this project. In the meantime, I will work on editing the book including its text, design and material form. I hope to be able to bring the book into the community to read it to its intended audience: children. I feel interacting with children in this way will provide me with the most salient feedback and will give me direction in the editing process.

Furthermore, I plan to continue exploring ways to incorporate sustainable themes into my Graphic Design work. A project I developed in conjunction with the book this summer is titled, *A Chance to See Through Different Eyes*. The work is a collection of colored pencil illustrations which represent eight of the most endangered species (Gorilla, Amur Leopard, Tiger, Sumatran Elephant, Orangutan, Rhino, Sea Turtle and African Wild Dog). They act as my own way of looking through the lens of an animal on the brink of extinction and communicating this experience to others. Awareness and advocacy again are central themes to this work and are words I hope to keep associating with the designs I create.



**Figure 19.** *A Chance To See Through Different Eyes.* Shannon Stanforth, 2019. Colored Pencil.

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# Analysis of the Role of Data in Agile Project Management Methodologies

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## Abstract

Data plays a role in many areas of agile project management methodologies. While there are three main methodologies within the project management realm such as waterfall, iterative and agile, agile stands out as a product-centric conduit of data outside of the realm of the other more traditional methodologies. Through features of agile methodology such as it's differentiation in project documentation and the frequency of stakeholder feedback as well as the types of metrics collected and the involvement of Project Management Offices (PMOs) with this specific methodology, agile collects and utilizes data in unique ways from other methodologies. Looking at the agents involved in facilitating the impact of data on agile projects and the types of and ways in which data is utilized, the role of this data is able to be observed. In looking at the impact specifically within Project Management Offices, we can see how varying PMOs are affected by the data being collected and how their influence helps channel data for the larger organization and the projects being ran either directly or indirectly through them. Within agile metrics such as velocity, burn up/burn down, and earned business value, we are able to indicate what types of information is being analyzed from the data collected in agile specific metrics and what or how organizational agents are consumers of these types of data. All of this helps paint a broader picture of the collection and utilization of data on agile projects and the influence it has on the larger organization.

## Literature Background

### Project Management Methodologies

Within the last half century, information systems and technology project management processes have revolved mainly around three methodologies: waterfall, iterative and agile (Hotle and Wilson 2018). These processes are segregated through their feedback loop styles and adaptability to changes in project scope. Waterfall, a process aligned towards a defined goal, is structured through a series of short-term goals that progress along a linear path. This type of methodology requires a large portion of up-front knowledge and is extremely reliant on the stability of the project. If there any changes or issues that arise during the project life cycle, it throws off the pre-planned project timeline and forces the project managers to reevaluate the structure of the project. This common limitation in project-based methodologies also affect the necessary resources such as time and capital for completion causing possible delays and budget expansion.

Incremental methodologies such as iterative and agile separate these goals into interdependent portions of the project. As the project life cycle progresses, pieces of the final solution are released

to the stakeholders ("A Guide to the Project Management Body of Knowledge" 2017). This is done within the general scope and timeline outlined at the beginning of the project. Feedback during these cycles occurs after the delivery of each increment, giving the project manager opportunity to change the project solution or timeline to fit the needs of the stakeholders. The iterative cycle fosters more frequent stakeholder feedback than waterfall since it takes in data about stakeholder experience and perceptions of the project periodically throughout the life cycle and adjusts the scope of the product accordingly. Where waterfall lacks in adaptability also, the iterative cycle allows for small adjustments to ensure a more viable solution/product for the stakeholders. While the iterative cycle lacks in ultimate flexibility and feature focused design, agile methodologies offer project managers a solution.

Agile methodologies take this incremental approach a step farther and presents products and solutions periodically throughout the whole project life cycle that are dependent on the client feedback loop and independent of the limitation of specific scope defining a detailed project structure ("A Guide to the Project Management Body of Knowledge" 2017). These periods are defined as sprints, each one composed with specific goals that satisfy certain features of the product. Unlike waterfall and iterative cycles, agile does not have a set vision of an end product at the beginning of the project lifecycle. Rather as sprints develop out certain features based off the feedback and needs of the stakeholder; an end product begins to form and incorporate all of the previous sprint developments into one final viable product that has already been tested multiple times by stakeholders throughout the cycle. *Figure 1* is a graph representing the above-mentioned methodologies based on a study conducted by Gartner of the average percentages that individuals believe their organizations use the three main methodologies.
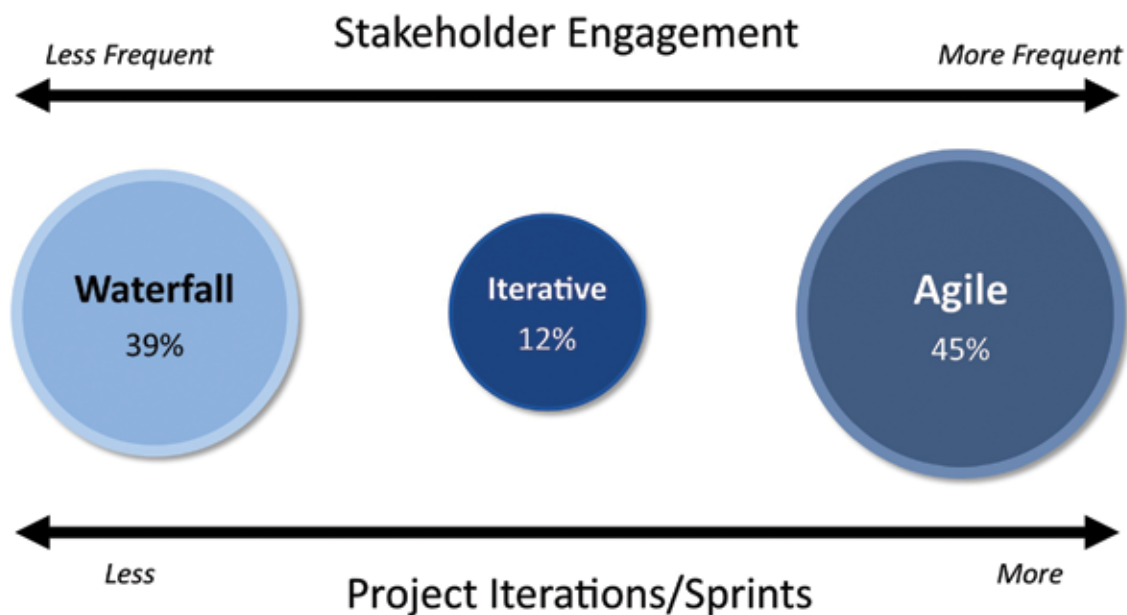


**Figure 1.** Differences in the Three Common Project Management Methodologies. Courtesy of Nolan Scott, 2019.

As the use of product-centric models such as agile methodologies are predicted to grow from 40 to 79 percent of organizations work being conducted by product-centric models by 2022, it is crucial that these project managers utilize effective techniques in managing and utilizing data (Hotle and Wilson 2018). The agile model mimics how humans process information and set about realizing their true wants and needs. While waterfall and iterative cycles cement a project manager into the stakeholder's upfront beliefs about a product's functionality and requirements, agile allows these to form over time as stakeholders come to realizations about their beliefs on what needs a final product should satisfy. Having more feedback loops with stakeholders and sprints developing the project cycle forces agile users to collect, manage and consumer more data than waterfall and iterative methodologies.

## AGENTS INVOLVED IN AGILE METHODOLOGIES

Outside of the individual stakeholders in a project, the main individuals affected by project methodologies are those constructing the solution, those overseeing the completion of the project, those setting the strategic direction for a firm, and the stakeholders impacted by the project or product. These can be broken down into the project workers who build the product, project managers who oversee the development and ensure a viable solution, project supervisors who verify the progress of projects and the quality of the product, and enterprises architects who are tasked with managing the direction of their firm and provide the tools and resources necessary on the firm's side for project completion. These roles serve the four functions within an organizational project management environment: strategy, portfolio, programs and projects and operations ("A Guide to the Project Management Body of Knowledge" 2017). When looking at the role data has on agile methodologies, it's important take into consideration the impact it has on the latter three types of individuals as they provide the most direction in data usage and management.

Project managers, also called project leads, are the employees most involved with the inflows and outflows of data within a specific project. They are charged with ensuring that individuals working on their project have the proper tools and resources necessary to complete each sprint and are responsible for maintaining the feedback loop with stakeholders on project progress and product elements. While the analysts and other employees on a project are the main users of actionable project data, the project manager is the main conduit for collecting and managing and utilizing the data. They are ultimately responsible for ensuring control data is being collected and that data is being used properly, preventing misuse and misinterpretation.

Project supervisors are a level above project managers and oversee the progress of one or more projects across a firm. While there is a variance in the supervision responsibilities and oversight capabilities of these individuals across different companies, their general role in data processing, specifically in agile methodologies, involves using both static and dynamic control data to ensure timely project delivery and client satisfaction. As controllers of many of the firm's internal resources, these individuals have the greatest capability in dispersing pre-held resources across the projects ran by the firm and thus maintain responsibility of the internal data collected that are held firm-wide and shared among multiple projects.

Enterprise architects are individuals such as the Chief Information Officers and other head strategists in firms regarding the use and control of data. These company executives help push the firm's tools and resources into the future and promote innovation and the continual development of project management techniques (Santos and Resnick 2018). Within agile methodologies and the incorporation into firm processes, enterprise architects lead the charge to shift focus from the project timeline to product development and channeling this into the individuals leading firm projects. While not actual project decision makers, enterprise architects build and train project managers and supervisors how to make these decisions



**Figure 2**. Project Agents in Organizational Project Management. Courtesy of Nolan Scott, 2019.

and how to manage the controls to determine the success of these decisions. In regard to data, these individuals are responsible for the overall firm's data integrity and the means in which that data is shared, managed and distributed. In utilizing data, enterprise architects observe macro-level metrics throughout the entire organization and trends impacting the strategic goals of the company. *Figure 2* depicts the responsibilities of the four levels of project management based off of the levels defined in the Guide to the Project Management Body of Knowledge.

## Data Types

For purposes of this research, I will specifically be focusing on data collected and utilized during the actual progression and completion of a project, excluding any project portfolio management that occurs at the beginning of most project life cycles. While there are many instances before and after a project when data plays a role, my analysis will be on the impact it has during the development and in the success metrics of a project.

In a study conducted in 2016 by the Journal of Modern Project Management, two main data types were identified as the main categories for data involved in project management: Static and dynamic (Vanhoucke, Coelho, and Batselier 2016). *Static data* refers to data collected at the beginning of a project, unaltered throughout the project lifecycle. This type of data is collected to determine information about the structure and needs of a project, giving us a picture of the project's environment. *Dynamic data* on the other hand is collected throughout the project progression as needed. This type of data can include metrics to determine successful sprints and features of a project and live data are involved in the project's process systems. *Figure 3* is a depiction of where static and dynamic phases occur in a broad project life cycle.
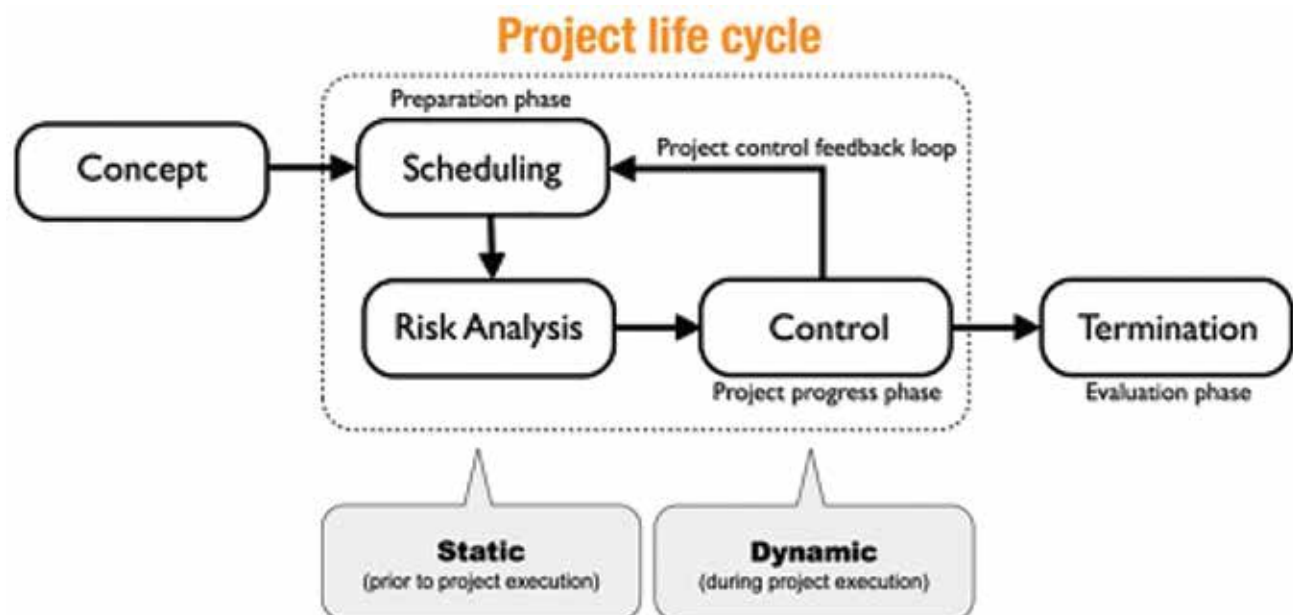


**Figure 3**. Static and Dynamic Data within a Project Life Cycle. Courtesy of the Journal of Modern Project Management, 2016.

Within static data exists several key component data points that encompass evaluation and management of projects within a larger organizational structure. These points exist within larger knowledge areas as defined by the Project Management Institute and includes integration, scope, schedule, cost, quality, resource, communications, risk, procurement and stakeholder management ("A Guide to the Project Management Body of Knowledge" 2017). Within these larger knowledge areas, four key metrics outline the greater management and evaluation of a project: time, cost, scope and value delivery. These metrics are defined at the beginning of a project during the initiating and planning process and allow project managers and other stakeholders to benchmark progress on specific projects and their resource absorption from the larger organization.

## Literature Review

### PROJECT MANAGEMENT OFFICE

Project Management Office's are an organizational tool created to serve a variety of purposes for an organization revolving around project and/or portfolio management. Over the past few decades, organizations have gravitated towards systemized processes in managing projects over the larger enterprises. The use of Project Management Offices expected to grow to 80 percent of organizations having some sort of PMO by 2023, indicating that organizations are centralizing their project management to an office of individuals that serve some sort of function in guiding the progression of enterprise projects (Stang, Schoen, and Henderson 2019). According to the Guide to the Project Management Body of Knowledge, these offices serve at least one of three functions for the larger organization: supportive, controlling and directive.

- Supportive PMO management is defined by the office acting as a resource for decentralized projects across the organization ran by departments outside of the specific PMO. These PMO's have limited decision making capabilities and control over these specific projects and act more as a data/information funnel for these projects. While they may receive specific metric data from these projects, they lack the power to execute on that information. (*Figure 4*)
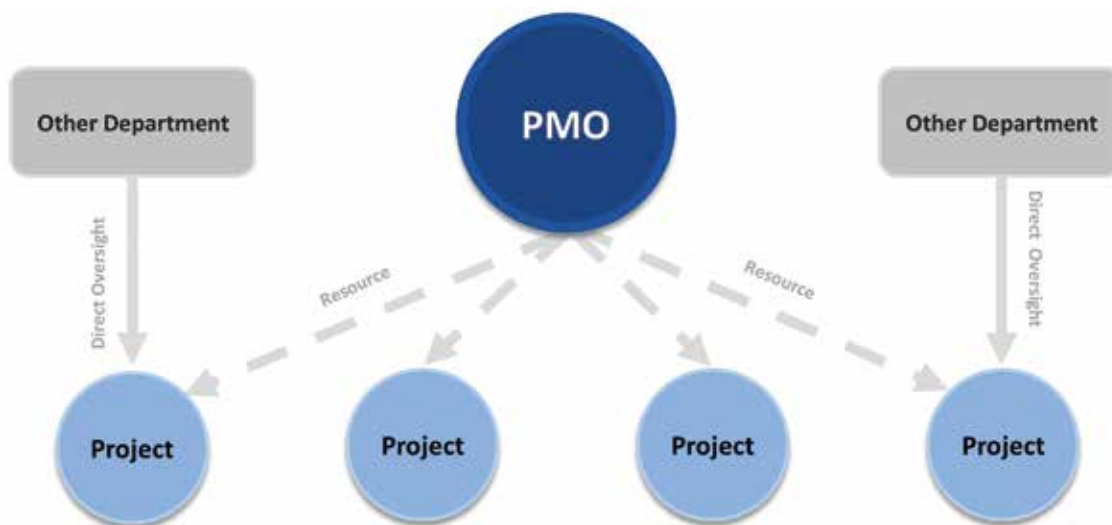


**Figure 4.** Supportive PMO Influence. Courtesy of Nolan Scott, 2019.

- Controlling PMO management is when the PMO has larger control over enterprise project management and can enforce practices across the larger organization. In this style of PMO management, the PMO is seen to act as a conductor for project management processes and organization. The data that these types of PMO receiving are typically more encompassing than the supportive style as they have direct governance over the methods and processes that these projects follow. With this, they also have the ability to act on the data received unlike the supportive PMO style and thus further the actionability of information derived from data collected on these projects. When it comes to the collecting data, this PMO style may dictate the collection of some of the data such as metric data that is necessary to provide indirect oversight but does so in accordance with what ever function it is trying to fulfill for the larger organization. (*Figure 5*)

- Directive PMO management directly manages projects throughout the enterprise and are the central point for all project management within the organization. This style of PMO directs the organizations project initiatives and the strategies and processes that projects follow within the organizations. The directive degree of control allows for standardized practices across the majority of the organization and serves as a central flow point for all data and information within project and cross projects. This allows for the collection of larger portfolio data and project metrics giving a macro view of the enterprises' project management practices. Within modern

developments in software organizations' enterprise architecture, PMOs have become structured as an executor for governance driven initiatives and have become increasingly involved in carrying out larger enterprise initiatives (Brand, Burton, and Mcgovern 2018). (*Figure 6*)
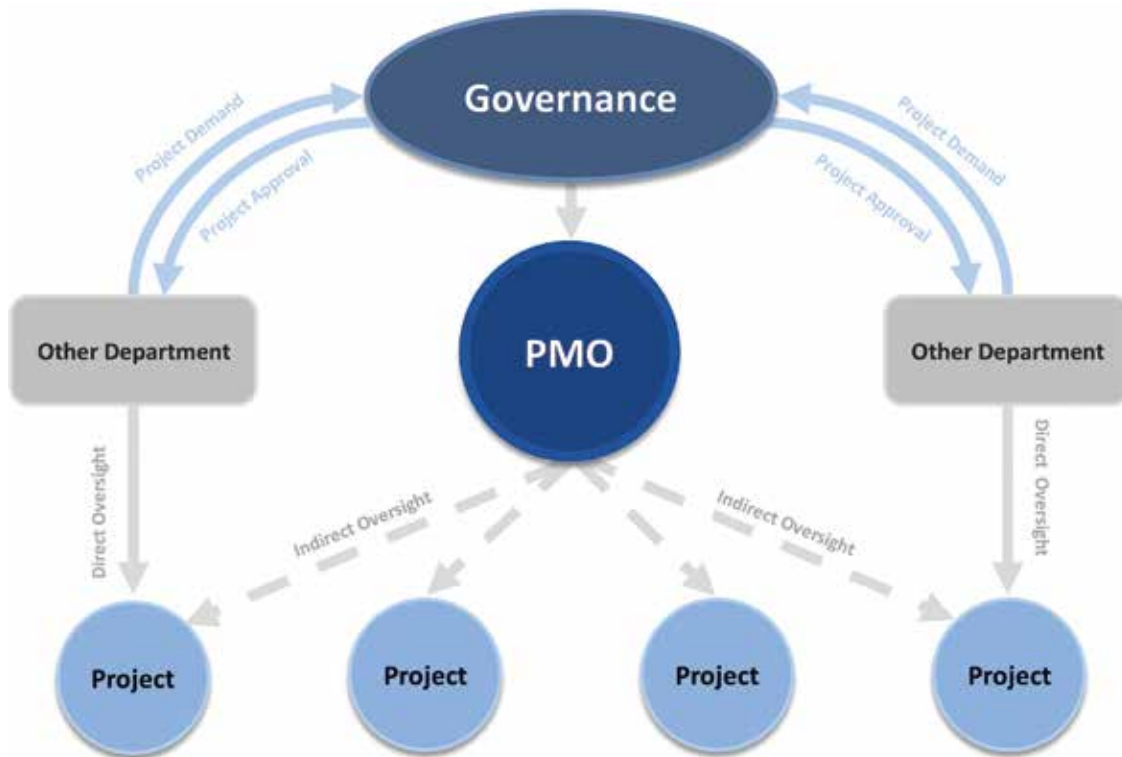


**Figure 5.** Controlling PMO Influence. Courtesy of Nolan Scott, 2019.
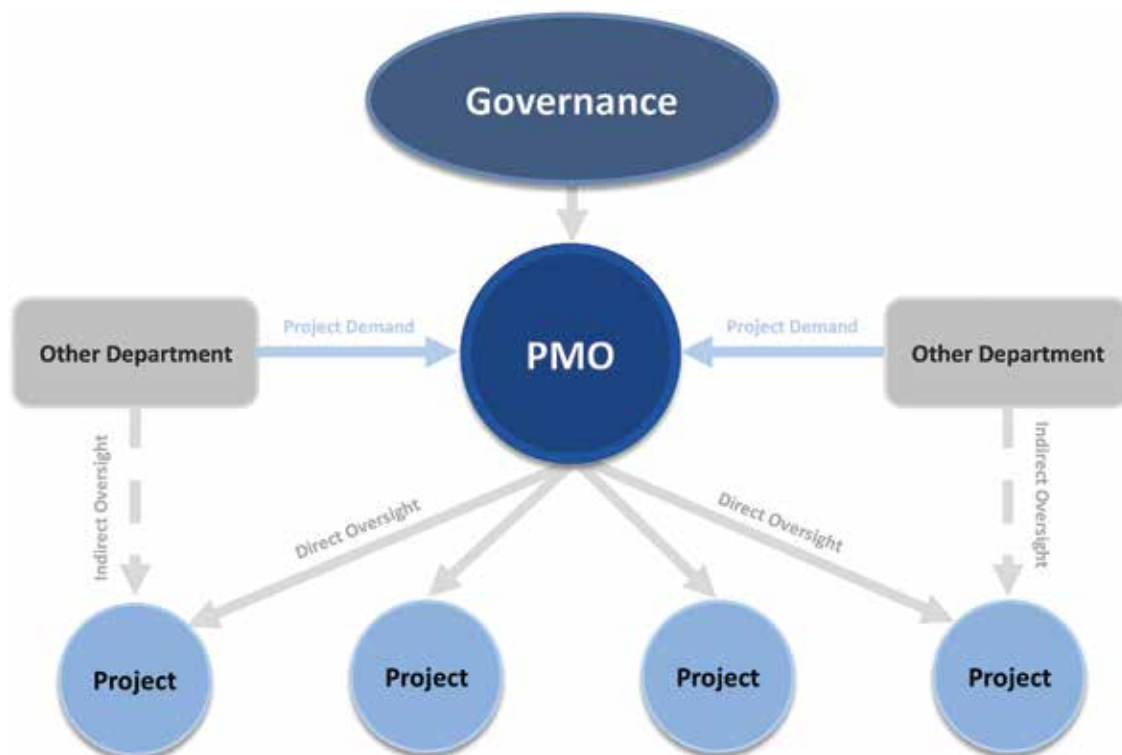


**Figure 6**. Directive PMO Influence. Courtesy of Nolan Scott, 2019.

The previous structures revolve around several functions that a PMO may serve for the larger organization. The functions of PMOs can serve to set project management standards, methodologies and processes, deliver projects and oversee programs, manage an organization's project management portfolio, generate and collect project management talent, collect metrics and controls to evaluate project performance, oversee organizational change management, provide administration and support for departmental projects, be a hub for knowledge management, and act as a strategic planning center (Letavec 2013). The structure of the PMO coupled with its functions within the organization determine what role it plays as a conduit for data. In agile organizations, these structures and functions can help facilitate the implementation of its methodologies and can be used as a hub for data within those projects.

## AGILE METRICS

As stated before, the vast majority of projects ran by organizations collect information from projects regarding its time, cost, scope and value delivery along with additional information about items such as project risk ("A Guide to the Project Management Body of Knowledge" 2017). These metrics are gathered in different forms within a project and are used in varying amounts depending on organizational priorities and capabilities regarding the collection of this data. In agile, these metrics take different forms and are collected in ways different than typical project-centric methodologies. In agile methodology, data such as cost, scope and time which are typically defined at the beginning with waterfall and measured against the initial value, are instead evaluated as the project progresses against the needs of the organization. This difference is due to the prioritization of the product within agile which causes variation in project progression. Variation as a result of features constantly evolving cause these metrics to be compared to an external value rather than a historic one. These external values are agile specific metrics such as velocity, burn up, burn down, defect density and earned business value (EBV) (Alderton 2012). The purpose of these agile specific metrics is to drive improvement, measure project effectiveness, evaluate quality and determine overall project impact on the organization (Swanton and Norton 2016).

Velocity in agile is a measurement of how quickly teams turn over features during a sprint and is used as a gauge to measure team productivity and efficiency. Unlike project-centric methodologies which do this by checking task completion or through task schedules, velocity allows agile to measure these same concepts without the need of a specific scope defined.

Burn up helps these same organizations measure the demand by stakeholders for specific features within the product. This data is collected to create a backlog of work that ideally is constantly being reprioritized and focuses on the features being added to the product. Project-centric methodologies measure this through a task list which is set to accomplish a specifically defined product. Agile allows these projects to adapt to the highest value features and prevent some of the waste that occurs through more traditional methods. Burn down charts, like velocity, help project managers see how many features are being completed. While velocity focuses more on the productivity of the team and how quickly these features are being turned over, burn down is a more effective measure of project completion.

Agile metrics such as running tested features and defect density help product owners and project managers determine the overall quality of the product based on the features introduced and the complications that stakeholders see when using the system. With this metric, project managers can measure how many issues are arising with the product features and as that number decreases over time, as issues are being resolved, the metric indicates that the project is closer to competition.

From the perspective of executive level individuals involved in the project such as the enterprise architects or even on a lower level, portfolio managers, earned business value is a key indicator on the value being drive from the project. Backlog completion in agile methodologies allow these individuals to measure feature additions against the ROI of a project to determine the overall value added to the stakeholders (Alderton 2012). This coupled with the burn up and burn down charts allow project agents to process the projects metric data and observe the overall impact of agile features and progression along with the impact to the organization.

## Acknowledgements

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# Development of a Computational Framework for Estimating Knee Joint Contact Forces in Walking and Running

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## Abstract

As primary modes of locomotion for human beings, walking and running (and more broadly, gait analysis) occupy a similarly central role in biomechanics. Many runners, however, are prone to unique lower-body injuries. An especial area of concern is the knee, as common among these injuries is knee pain as a result from high impact on the ground or ground reaction forces (GRF) [8]. These forces are altered by the foot strike pattern (FSP) of the individual and as a result will impact internal forces upward through the body. Given the complexity of the motion of running and the forces involved, it is useful to apply computational modeling to study the underlying mechanical aspects of walking and running. The OpenSim software for musculoskeletal modeling provides many of the resources required to create and test such actions [4]. Using marker data and ground reaction force data, a simulated model and various computational tools allow for measurements physically impossible *in vivo*; specifically, the compressive tibiofemoral force that may have adverse effects on tissues such as articular cartilage or menisci. The overall goal of this work is to measure and compare tibiofemoral forces in female runners in walking and running using a rearfoot strike (RFS) versus a forefoot strike (FFS). For each trial of each runner, an appropriate model will be developed and analyzed, which requires large amounts of calculation and optimization. To begin this process, the specific focus of this study was to assemble a data processing pipeline within OpenSim and begin to integrate OpenSim processes with MATLAB in order to streamline data processing.

## Discussion

Running is one of the most common forms of exercise but is vastly more complex when compared to other movements due simply to the number of muscles, bones, and joints and the coordination required to coordinate them [11]. The frequency and intensity of the exercise is such that between 37 to 56 percent of runners experience overuse injuries annually [8]. Even the seemingly benign action of walking subjects the knees to up to three times body weight in compressive force [6], which is only compounded in running. As there are so many factors that contribute to the action of running, there are several parameters that may be adjusted to decrease joint force and thereby optimize running technique.

Previous studies have investigated the differences between foot strike patterns in the biomechanics of runners [1]. There are three main types of foot strike patterns, and the difference can be easily discerned by viewing the strike in the sagittal plane. The most common type is rearfoot strike (RFS), used by the vast majority of long-distance shod runners [8]. In RFS, the heel is the first part of the foot to hit the ground, and the foot "rolls" along the ground, culminating with a "toe-off" at the end of the strike. RFS implies

strong distal activity of dorsiflexor muscles [2]. The opposite is true for a forefoot strike (FFS), where the toe area is the first part of the foot to contact the ground, and results in greater plantaflexor muscle activity [2]. While FFS is not the instinctive gait for most people, there are benefits linked to using a FFS over a RFS pattern: Milner et. al advocated FFS in order to prevent injury, as the strike pattern was linked to lower vertical ground reaction forces (GRFs) [10], which are used as an approximation for lower extremity loading [1]. FFS also demonstrated lower patellofemoral contact forces and patellofemoral stress [8]. Of course, the trade-off is merely a transfer of energy. The knee performs less work in FFS than in RFS, but this work is transferred to a higher-performing ankle [3]. It has also been proposed that FFS exercises both greater elastic energy storage and return in significant nearby structures such as the Achilles tendon and medial longitudinal arch. However, FFS users displayed reduced stride length and gait speed [2]. FSP modification is a promising area for injury prevention and treatment [1], and FFS kinematic differences are not significant between learned and intrinsic FFS users [3].

There exist noncomputational methods for determining knee loading. The least preferable is of course physical measurement, which is uncomfortable for patients or invite unnatural movement due to the invasive nature of the instruments involved. In consideration of alternative muscle loadings, smaller knee abduction moment has been measured in the frontal plane for FFS. Greater knee abduction moments can lead to greater contact force loading on the knee, which are linked to knee disorders such as medial tibiofemoral osteoarthritis. Still, knee abduction measurements are not a direct indicator of medial compartment loading and have had mixed success [14]. Alternatively, patellofemoral contact force can also be understood as a function of knee flexion and quadriceps force, which allows for a singular polynomial expression of the resultant contact force [8]. In this study, more accurate computational estimates will be calculated for knee joint loading. Specifically, the software used is OpenSim, an open-source platform that allows users to create, modify and analyze models based on experimental data [4]. The nature of the software has allowed contributors in the biomechanics community to create and add their own plug-ins for individual projects. Some, like tools for calculating joint forces or muscle accelerations or power, are included with the baseline install of OpenSim because the application is so broad [4]. OpenSim is useful for gait analysis and has been used to calculate compressive tibiofemoral force successfully [13].

The data for this study were collected from twenty-four healthy females between the ages of 18-35 with a habitual RFS [9]. Participants with a lower extremity injury within the past year were excluded. Wearing New Balance 10v1 Minimus Trail-Running shoes, participants had markers placed in significant areas: pelvis, right thigh, shank, and foot. The first trial was a static trial for scaling purposes, followed by five trials of RFS walking. After this, participants were instructed to switch to FFS walking. The same procedure was repeated for RFS and FFS running. Marker trajectories were tracked by an 8-camera Vicon Motion Capture System (Oxford
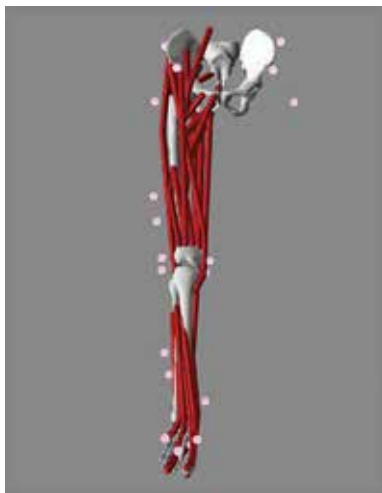


**Figure 1.** An OpenSim model used for analysis. There are 43 actuators that make up the model's muscle set, depicted here as red lines. The markers used for motion capture are depicted in pink. Courtesy of Sean Kapp (via OpenSim), 2019.
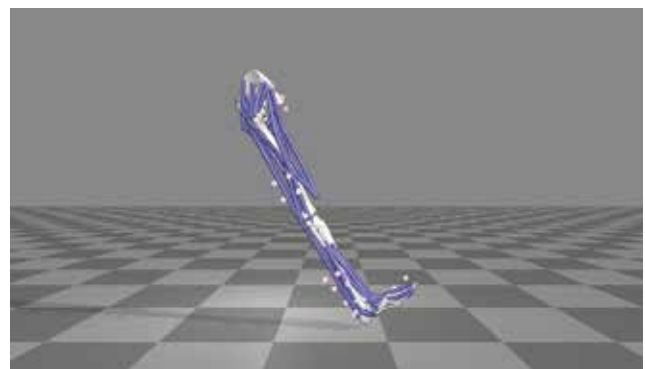


**Figure 2.** An OpenSim model posed with marker data from an Inverse Kinematics analysis. This model is at the start of the trial, about to enter stance phase with the right leg. Courtesy of Sean Kapp (via OpenSim), 2019.

Metrics, UK) at 150 Hz. Ground reaction force was captured at 1500 Hz by a force plate in the floor (Bertec Corp., Columbus OH, USA). The marker and force data were collected during right leg stance phase. In MATLAB (Mathworks, Natick, MA, USA), marker data were low-pass filtered by a 4th order Butterworth filter at 10 Hz. Force plate data were filtered in the same way at 50 Hz.

With the data filtered and prepared it is ready to be used in the OpenSim software. In addition to the experimental data, a pre-existing computational running model was modified to match the body segments and markers captured in the data set. With data for each participant and trial and the generic OpenSim model, the steps to apply the data and analyze the joint reaction force are identical from trial to trial.

The first step to generate an accurate model is scaling. The same markers are present virtually on the OpenSim model as were present on the human participant at the time of data collection. As opposed to using any manual scale factors, the scale tool uses pairs of markers to determine individual scale factors [4,12]. The scale tool uses these scale factors to redefine body geometry. The skeletal structure of the model is scaled up or down, and mass properties and muscle attachment points with it. The muscles themselves also undergo scaling, although iteratively this task is completed after components that do not depend on length. After the parts of the model are scaled appropriately, the virtual markers on the model before the tool is run are moved into experimental positions from the static trial [4,12].

Once the model is appropriately scaled, trials of actual movement can begin to be processed. The first step to analyzing movement is to run the Inverse Kinematics tool to describe the model's joint angles over the time frame of the trial. By breaking the marker data into individual frames, the Inverse Kinematics tool matches the pose outlined by the markers by solving a least-squares problem. [4,12] In this study Inverse Kinematics is run without prescribed coordinates and equal weighting for all coordinates.

For the gait models used in this project, there is a disparity between the number of degrees of freedom of the model and the joint actuators that are present as a results of model components. OpenSim presents the six degrees of freedom between the model's pelvis and the ground as a

joint with six respective torque actuators [4,12]. With the addition of these torque actuators there exists an actuator for every degree of freedom. The translational forces in the x, y and z directions applied to the pelvis-ground joint are referred to as "residuals." Dynamic inconsistency will still arise when a model does not completely match the real-life motion of an object. A simplified model like the one used in this study may not contain all the data necessary to account for the totality of GRF. Noise or other errors from motion capture may also contribute. An especially significant aspect of honing the computational model to reflect real-life behavior is reducing these residual forces in order to assuage dynamic inconsistency and satisfy Newton's Second Law, which here is expressed as

$$\vec{F} + \vec{F}_{residual} = m\vec{a}$$

For the model to be accurate, the residual force term should be as small as possible. The Residual Reduction Algorithm works to accomplish this by adjusting the mass center of the model and recommending adjustments to model segment masses and kinematic results. The algorithm iterates through every frame of the Inverse Kinematics results and compares the accelerations and comparing the force applied by all of the model's actuators to the required force to move it from step to step. This process also incorporates GRFs [4,12]. There are no experimental data in this set to inform the position of the torso, so the most accurate assumption is for the mass of the participant's torso to be applied at the center of mass of the pelvis. In this configuration the Residual Reduction Algorithm is able to run and produce results that are within acceptable parameters [4,12].

Before the specific knee joint can be analyzed, the contributions to contact force by individual muscles must be known. The model's motion is completely understood from the kinematic results of previous tools: position, velocity, and acceleration. The Static Optimization tool minimizes the objective function:

$$J = \sum_{(m=1)}^{n} (a_m)^p$$

subject to the constraints of the ideal force generators:

$$\sum_{(m=1)}^{n} [a_m F_m^0] r_{m,j} = \tau_j$$

where n is the number of muscles in the model; am is the activation of muscle m at a discrete time step, $F_m^0$ is its maximum isometric force, $r_{m,j}$ is its moment arm about the $j^{th}$ joint axis; $\tau_j$ is the generalized force about the $j^{th}$ joint, and p is a defined constant (in this study, 2) [4,12]. Because compressive force on a joint is not merely the result of ground reaction force; muscle contributions to joint force are far from trivial [7], and specifically, tibiofemoral force has been shown to reduce with altered muscle activations [5], the Static Optimization profile is essential for obtaining accurate results.

The next step is to finish Static Optimization by adjusting parameters until the muscle activations are consistent with established literature [6]. After this force profile is obtained, the Joint Reactions Analysis tool will be used to report tibiofemoral force. By using the OpenSim/MATLAB API, the process will be made more streamlined so that more data can be processed more efficiently. Overall the goal is to compare FFS and RFS running and walking by using this data pipeline. With a more accurate picture of how FSP influences knee contact force, FSP alteration can be more accurately used to prevent and treat injury.

## Acknowledgements

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# 3D Printed Hyperelastic Polymers: Constitutive Modeling and Finite Element Implementation

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## Introduction

The field of additive manufacturing has advanced in method and capability to enable quick, specific 3D printing of soft, stretchy materials. These recently developed hyperelastic polymers are generally undefined in terms of a working characteristic model for predicting material responses in various stress states.

My work over the summer involved building an understanding of the 3D printing of hyperelastic materials with a general literature review while learning the procedure for and value of the material modeling process and finite element analysis (FEA). I worked with and within Dr. Robert Lowe's Mechanics of Advanced Materials and Structures (MAMS) Lab and partnered with a team at the University of Dayton Research Institute (UDRI).

Recent developments have brought about experimental resins of polymers with remarkable elastic properties. Highly elastic materials are valuable for a multitude of applications requiring large but recoverable deformation. These soft materials have the potential to open doors in the fields of impact resistance and energy absorption with their particular properties and behavior under applied stress.

## Soft 3D Printing

Applications in sports equipment, soft robots, and human-assistive devices all call for high strength, lightweight materials which can endure impact and wear in their respective unique situations and conditions [1]. Soft, hyperelastic materials are promising prospects to fill these roles, especially when fabricated as cellular structures. Cellular structures, or lattice structures, are patterned arrays of a specific shape or configuration. A unit cell is repeated to form a tessellation across the face and through the width of the material. These formations use less of the raw material to fill the same volume, as air space exists in the gaps left by the design. A common and effective example of a lattice structure is a hexagonal lattice, or a honeycomb (See *Figure 11*).

Honeycomb geometries are valuable in their derived strength and naturally lower weight than a solid block of a material, thus forming a polymer into a honeycomb structure would ideally result in favorable properties for the previously stated applications. I chose to explore using a honeycomb geometry for this reason. However, the advantages associated with lattice materials come paired with challenges in achieving the complex geometries that are often incompatible with traditional methods of manufacturing. Thankfully, 3D printing opens the door for fashioning complex geometries [2]. The unique chemical and material properties

of these novel hyperelastic polymers allow for efficient 3D-printing through continuous liquid interface production (CLIP). A subset of digital light processing (DLP), both CLIP and DLP utilize a photocurable liquid resin. Exposing the resin to UV light in a pattern of cross sections of the desired part allows the process to gradually form the entire geometry. CLIP distinguishes itself from other forms of DLP by requiring resins with a specific viscosity and whose curing process is oxygen inhibited [3]. The CLIP process is pictured in *Figure 1* and involves a build plate dipping down into a liquid resin bath and rising out of it, pulling cured layers upward with it. A projector shines UV light onto hundreds of small mirrors which angle to focus the light into the shape of the current necessary cross section of the part geometry.
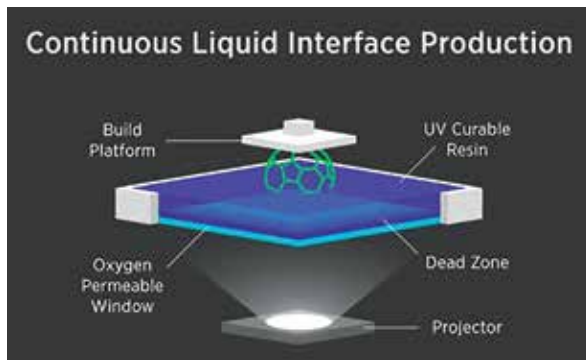


**Figure 1.** CLIP illustrated. Courtesy of The Technology House, tth.com/carbon-clip/, 2019 [4].

Continuous building is made possible by the aforementioned properties of the hyperelastic resin. A certain viscosity allows the liquid to follow itself as it is pulled out by the build plate and the layers of resin above. Thus, the space left by the cured resin layer is replaced by liquid resin, ready to be solidified into the subsequent cross section. Unique to CLIP is the use of a resin bath. Traditional DLP involves a single layer of liquid resin, UV curing, and lifting of the build plate to allow another layer of liquid to be applied to the curing surface. The use of a resin bath is made possible by oxygen inhibition of the curing process. The UV light is projected through the entire liquid resin bath, yet only the top layer is cured as a result of the polymer chemistry. CLIP saves time with its continuous nature and results in less waste of the build material. Even as additive manufacturing is favorable in speed, sustainability and capability, the process has been plagued with issues of repeatability [2]. Variability in different prints of the same

geometry and anisotropic behavior exhibited in individual prints themselves limits the effectiveness and reliability of 3D printing. Until there is evidence demonstrating a reduction or elimination of these issues, 3D printing will struggle to evolve beyond a method for rapid prototyping.

## Experimentation

The variance in the build of a part as been found to be influenced by the 3D printing process parameters [5]. Layer thickness, extrusion temperature, build orientation and post-curing time all influence part integrity to different extents, depending on the type of 3D printing and material involved. Layer thickness, or resolution, and build orientation are specifically pertinent to CLIP. Resolution is pictured in *Figure 2* and refers to the width left at the top of the resin bath above the dead zone created by the cure-inhibiting oxygen. CLIP is continuous and therefore layerless compared to the other methods of 3D printing. The different build orientations are shown in *Figure 3*.

Printing and testing sample sets of tensile specimens with all combinations of resolutions and orientations adds to current literature on the reliability of additive manufacturing processes [1].
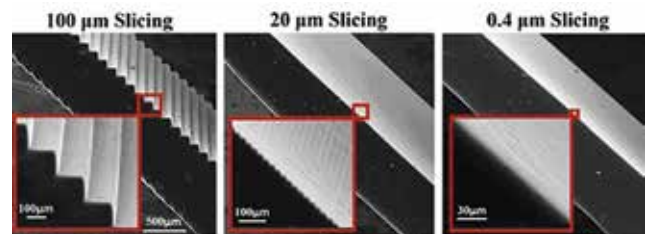


**Figure 2.** Higher resolution correlates with a thinner layer thickness. Courtesy of Janusziewicz et al., 2016.
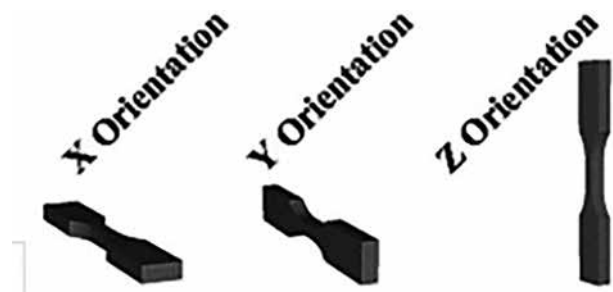


**Figure 3.** Printing orientations. Courtesy of Janusziewicz et al., 2016.

Tensile testing outputs an experimental stress-strain relationship for the tested material, which can be converted to a stress-stretch relationship for the specific case of hyperelastic polymers. These experimental relationships are not universal, rather specific to tensile stress states. Even so, they still act as valuable inputs for hyperelastic models. My work this summer centered on the analysis and post-processing of results that would come from this type of experiment. Although the MAMS lab or our partners at UDRI were never able to conduct the experiment as planned, I was still able to move forward with my research using the Treloar data pictured in *Table 1*, an experimental stress stretch dataset gathered from testing vulcanized rubber [6].

**Table 1.** Treloar's data for uniaxial tension testing of vulcanized rubber Courtesy of Steinmann et al., 2012.

### uniaxial tension

| λ [ ] | P [MPa] |
|-------|---------|
| 1.00 | 0.00 |
| 1.01 | 0.03 |
| 1.12 | 0.14 |
| 1.24 | 0.23 |
| 1.39 | 0.32 |
| 1.61 | 0.41 |
| 1.89 | 0.50 |
| 2.17 | 0.58 |
| 2.42 | 0.67 |
| 3.01 | 0.85 |
| 3.58 | 1.04 |
| 4.03 | 1.21 |
| 4.76 | 1.58 |
| 5.36 | 1.94 |
| 5.76 | 2.29 |
| 6.16 | 2.67 |
| 6.40 | 3.02 |
| 6.62 | 3.39 |
| 6.87 | 3.75 |
| 7.05 | 4.12 |
| 7.16 | 4.47 |
| 7.27 | 4.85 |
| 7.43 | 5.21 |
| 7.50 | 5.57 |
| 7.61 | 6.30 |

## Constitutive Modeling

A hyperelastic model hopes to predict a hyperelastic material's deformative response to applied stress states. Defining a perfect hyperelastic model would allow accurate predictions as to how a hyperelastic material would behave when different stresses are applied. Ideally, compression tests could be run on a sample, the results could be extrapolated with a model, which would yield predictive values as to how the material would behave in tension or torsion. Unfortunately, the perfect hyperelastic model does not exist, but many different models have been formulated attempting to capture hyperelastic behavior, with each performing better than others situationally [7]. Theory and specific assumptions allow a derivation of a stress-stretch relationship from the elastic strain energy function (W). Assuming incompressibility, the strain energy becomes a function of strain invariants $I_1$, $I_2$, and $I_3$. The invariants are themselves functions of principal stretches as shown in *Figure 4*.

$$I_1 = \sum_{i=1}^{3} \lambda_i^2$$

$$I_2 = \sum_{i,j=1}^{3} \lambda_i^2 \lambda_j^2, \quad i \neq j$$

$$I_3 = \prod_{i=1}^{3} \lambda_i^2$$

**Figure 4.** Strain invariants as functions of principal stretches. Courtesy of Martins et al., 2006.

Choosing to specialize the model for the stress condition of uniaxial tension as well as considering incompressibility allows the principal stretches, and therefore the invariants, to be defined as functions of $\lambda_1$. Assuming isotropy gives stress as the function in *Figure 5*, which is in terms of the original strain energy function, permitting the necessary substitutions and expansions for a final stress-stretch relationship.

$$\sigma = 2\left(\lambda^2 - \frac{1}{\lambda}\right)\left(\frac{\partial \Psi}{\partial I_1} + \frac{1}{\lambda}\frac{\partial \Psi}{\partial I_2}\right)$$

**Figure 5.** A general function for a hyperelastic polymer's stress stretch relationship. Courtesy of Martins et al., 2006.

Using the Yeoh hyperelastic model shown in *Figure 6* as an example, note the inclusion of constants $c_1$, $c_2$ and $c_3$.

$$\sigma_{\text{Yeoh}} = 2\left(\lambda^2 - \frac{1}{\lambda}\right)\left(c_1 + 2c_2(I_1 - 3) + 3c_3(I_1 - 3)^2\right)$$

**Figure 6.** Yeoh's model for a hyperelastic's stress stretch function. Courtesy of Martins et al., 2006.

These are tunable parameters that allow the models to be fit to a specific dataset. For my purposes, this dataset is Treloar's. With the curve fitting tool *lsqcurvefit* in MATLAB, I generated curves for each hyperelastic model with the least sum of the squares of differences from the experimental values. The unknown constants are decided by this process of curve fitting, as whatever combination of values is necessary to create the least error of squares will be set. The plotted curve represents the model's outputted prediction for the stress stretch relationship of the inputted material under the chosen stress state. All of the data and models shown in *Figures 7 and 8* deal with uniaxial tension. Naturally, the closer the model's prediction is to the colored black experimental data curve, the better the model is for predicting that material's response in uniaxial tension.
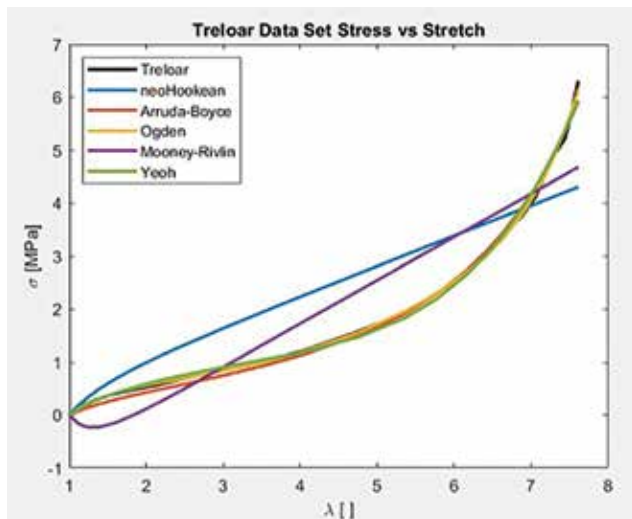


**Figure 7.** Comparative graph of modeled and experimental stress stretch functions. Courtesy of Kevin Lawson, 2019.

The Arruda-Boyce, Ogden and Yeoh models all appear to do quite well, to the point of covering the black line representing Treloar's data entirely. The Mooney-Rivlin model oddly dips into negative stretch, which demonstrates the purely mathematical process of simple material modeling [6]. This result is nonphysical, yet the model and least squares curve fit function does not inherently have a check to prevent that result from outputting. Fixing the outputs to sensible predictions requires user input in model-specific consistency equations. I demonstrate the small strain convergence method in Figure 8.
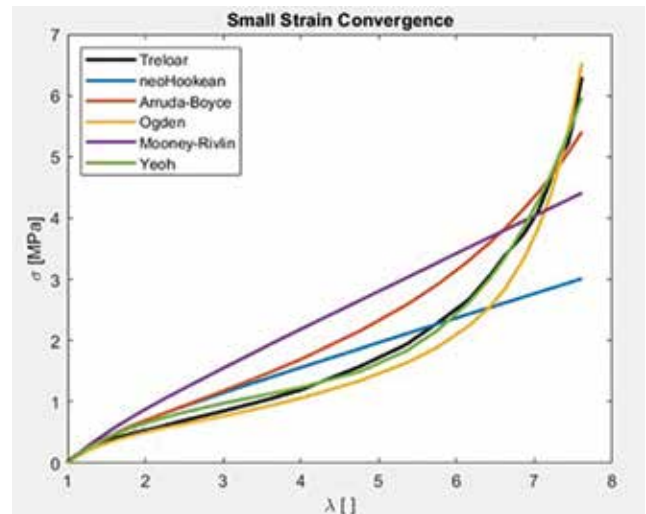


**Figure 8.** Hyperelastic models with small strain convergence. Courtesy of Kevin Lawson, 2019.

As shown, this process forces the models to fit the initial slope of the experimental data by setting the derivative of the hyperelastic model equal to a value found with a forward difference of the first two values of Treloar's stress and stretch data. Although this seems to offset more of the models from the black line than brings others closer, all models visibly follow the same slope at small stretch values. It appears logical and simplest to use the Ogden, Arruda-Boyce or Yeoh model without the small strain convergence for this material as they seem to follow the experimental data almost exactly. Still, it is important to remember how this dataset and these subsequent predictive models are only inclusive of the uniaxial tension stress state. Although a model may preform well with one deformation mode, this is no guarantee for others, such as compression or torsion [7]. A predictive model is most confidently chosen with the process completed with testing and data analysis for all stress states and a least-squares calculation. Without the testing capabilities for this process or access to a hyperelastic material to test, my work on understanding the constitutive modeling

process was more so complementary in nature with how it branches from the experimental side and connects into post-processing techniques.

## Finite Element Implementation

Finite element analysis (FEA) is a series of steps resulting in a simulation based on user inputted geometries, properties and boundary conditions. FEA references the entire process of forming part geometries in a CAD software, discretizing the parts with a meshing software, defining boundary conditions in pre-processing, running the simulation, and viewing results in post-processing. LS-DYNA (version R10.1.0, LSTC, Livermore, CA) is the supercomputing program that runs the user defined simulation and generates resultant animations and information. The perfect simulation precisely replicates what would happen in real life while avoiding the time and material cost of setting up such a test. Again, unfortunately, the perfect simulation does not exist. The goal is to come as close as possible to replicating real life, which involves precise inputs to direct the programing to understand the nature of the materials, shapes, velocities and surfaces involved. The FEA process is visually outlined in *Figure 9*.
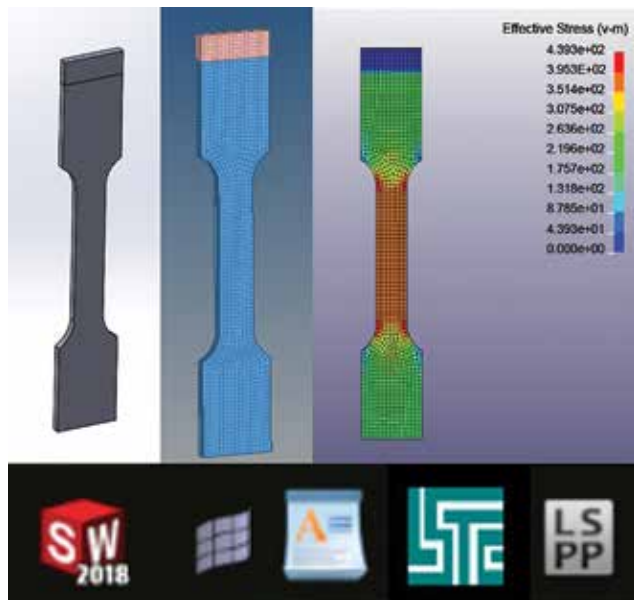


**Figure 9.** The FEA process for a tensile test simulation. Courtesy of Kevin Lawson, 2019.

To begin, I worked in Solidworks (2019 version, Dassault Systems, Waltham, MA) to create 3D CAD file geometries of the necessary parts for testing. It was useful to begin with simulating a tension test, so I built a tensile specimen according to ASTM D412, the standard for tension testing of hyperelastic materials. The block joined to the top of the specimen is a simplification of the grips of the load frame. Outputting the geometry as an IGES file allows it to be imported into Hypermesh (2017 version, Altair, Troy, MI), the meshing software I used for the discretization of my parts. With an automeshing tool, I generated separate grids over the tensile specimen and the attached grip. Dragging the grids through the width of the parts created 3D meshes comprised of individual nodes and elements, the surfaces outlined by the nodal formation. Hypermesh also allows the creation and assignment of boundary conditions for the simulation. Eliminating the edge at the boundary between the grip and tension specimen forces the nodes along that border to combine and thus move together. Removing all degrees of freedom from the bottom surface of nodes of the tensile specimen defines that surface as rigid. With these conditions set in place, the file can be exported as an LS-DYNA solver deck. A solver deck is LS-DYNA's input for a simulation and is made up of individual cards. Each card defines a piece of information that the LS-DYNA program references to build the simulation as the user describes. The deck acts and feels like a code, as structure matters and there are specific keywords and abbreviations. The deck works as an input to supply the supercomputing program with the information required for the simulation, yet it outputs from Hypermesh as a generic text file. My alterations to the cards and set up of the solver deck were completed in Wordpad (version 1903, Microsoft, Redmond, WA), including defining parts, materials, velocities and output conditions. For the tension testing example simulation, two part cards exist, one referencing the tension specimen and one for the grip. An example part card of the tension specimen is featured in *Figure 10*.

Within the part cards, a section card is referenced in *secid*, defining each part as a shell or a solid type. A material card is also referenced with *mid*, ordering the LS-DYNA program to treat each part as behaving according to the properties described in the material card. The material card is the most important and most difficult card to define and structure

```
*PART
Tension specimen
$#       pid       secid           mid       eosid         hgid         grav       adpopt         tmid
          1           1             1           0            0            0            0            0
```

**Figure 10.** Sample part card representing a tension specimen. Courtesy of Kevin Lawson, 2019.

correctly as they are based on the previously described material models. This connection will be explained in further detail in a later section. I described velocity in a *BOUNDARY_PRESCRIBED_MOTION card, which references a part ID for which part the velocity applies to. For the tension test, a constant velocity is applied to the grip part in order to imitate the movement of a load frame in a real-world tension test. As the base of the tensile specimen was defined as rigid in Hypermesh, and the nodes on the border between the grip and specimen were made equivalent, the velocity applied to the grip causes elongation in the tension specimen over time. Control cards and Database cards work to define simulation logistics. The run time is set in a *CONTROL_TERMINATION card, and the *DATABASE_BINARY_D3PLOT card prompts LS-DYNA to record the results of the simulation in a d3plot file. A d3plot file is the output file that can be opened in LS-PrePost (2018 version, LSTC, Livermore, CA) and produces the simulation animation and corresponding viewing options. The multi-colored tensile specimen in *Figure 9* is an example of a d3plot file of a simulation of normal termination modified to display Von Mises stress. In this proof of concept tension test simulation, the specimen was modeled with the *MAT_ELASTIC material card, meaning the part was limited to linearly elastic deformation. This is unreasonable for modeling hyperelastic materials, which have little to no range of linearly elastic deformation [8]. Using the proper material model is the most significant factor in determining how accurate a simulation will be, especially for how problematic modeling a soft material becomes.

## Honeycomb Modeling

The next step for my work with FEA was to build on my process for simulating a tension test with a more complex, applicable simulation. My project expanded to modeling a compression test on a honeycomb lattice structure. The procedure was similar in terms of building a 3D geometry in Solidworks, meshing the structure in Hypermesh, preparing the code in WordPad,

running the simulation with LS-DYNA, and viewing the output file in LS-PrePost. A patterning tool helped me efficiently form the honeycomb lattice shown in *Figure 11*.
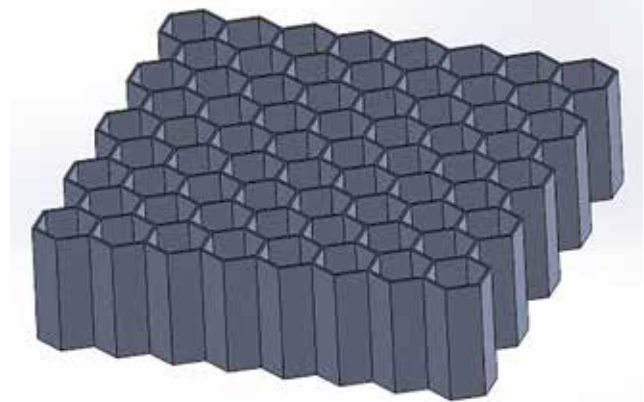


**Figure 11.** 3D CAD drawing of a honeycomb structure. Courtesy of Kevin Lawson, 2019.

A compression test differs from a tension test in the required components with regards to number of parts and cards in the solver deck. Compression platens need to be included in the model system for the honeycomb sample to have something to compress into. I sketched and extruded wide, thin cylinders to import into Hypermesh with the honeycomb for meshing and constraining. The cylinders should be defined as rigid to mirror a real world compression test, where the hardened steel platens would have negligible deformation compared to the honeycomb sample. The honeycomb lattice was created with reference to a similar experiment on 3D printed honeycombs in which a pattern of 64 cells, 9 rows was utilized, which is the minimum number of cells necessary to replicate the behavior of an infinite lattice [1]. Meshing the geometries in Hypermesh yields the arrangement in *Figure 12*.

This simulation requires additional cards to be included in the solver deck as it is a compression test. The LS-DYNA program must be instructed in how to deal with contact between parts, mainly which parts meet and the nature of that interaction. Another variation in this simulation is the material model I chose to use to define the
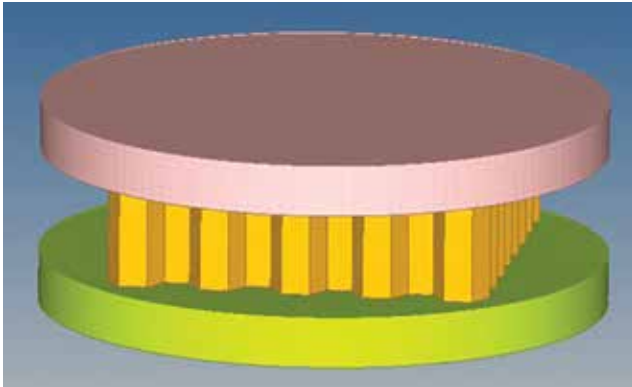
**Figure 12.** The platens and honeycomb are represented by nodes and elements. Courtesy of Kevin Lawson, 2019.

honeycomb with. Instead of *MAT_ELASTIC, the honeycomb was detailed with the material card *MAT_PIECEWISE_LINEAR_PLASTICITY, a material model which builds the stress strain function with linear piecewise segments. Piecewise linear plasticity is of higher order than a *MAT_ELASTIC card as it has a greater capacity for capturing the curve of a stress strain function and includes a failure model for the simulation. Unfortunately, this model is still inaccurate in predicting the behavior of hyperelastic materials, and my goal of fashioning a soft honeycomb lattice compression test was not realized over this project's timeline. Inputting soft material properties can cause warping in the geometries and error out the running of the simulation with miscalculations of negative volume. In order to achieve a normal termination for the honeycomb compression test and generate a quality proof of concept simulation, I substituted hyperelastic material properties for that of aluminum. The stiffer material reacts more predictably to a compressive force and resulted in the animation conveyed by the three frames featured in *Figure 13*.

## Future Work

Going forward, there are many opportunities to continue with this project in terms of experimentation, constitutive modeling, and work with FEA. Once UDRI receives hyperelastic resins, the previously described experiment can move forward with printing and testing tension specimens. The tests will output data to be processed and plugged into material models, familiar or foreign. There are many more material models that I did not have time to explore with their own derivations and
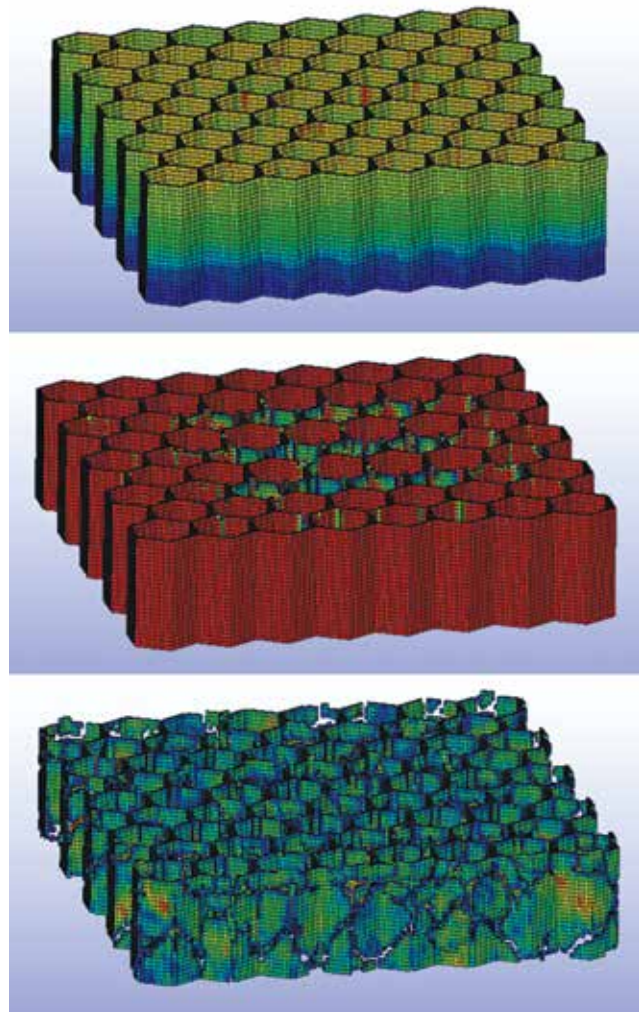


**Figure 13.** Stages of the compression test simulation output. Courtesy of Kevin Lawson, 2019.

consistency equations which may model our specific hyperelastic polymer more accurately than the ones I have considered already. The FEA simulations I created over the course of this project were building blocks leading to future tension, compression or impact testing of greater complexity. Familiarizing myself with new, more detailed material cards and adding checks for issues prompted by modeling soft materials will allow me to create more precise, relevant simulations.

## Discussion

Additive manufacturing is an expanding field with many gaps in understanding and relevant research, specifically in regard to printing soft materials. Hyperelastic polymers are materials with evolving applications due to their unique properties and recent advancements in material configuration. Likewise, lattice structures, with their advantages and feasibility in their connection to the capabilities of 3D printing, spin the applications of soft materials in new directions. Material modeling and FEA are developing methods for predicting the behavior of new materials and geometries, aiding the product development process and transition of experimental hyperelastic polymers into practical applications. This project dips into every aspect of development for these soft materials, and there is much to do going forward.

## Acknowledgements

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# The Communal Integration of Cultural Assets to Combat Dietary-Related Health Disparities within the Latinx Population

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## Abstract

Due to a series of social determinants, the Latinx population currently living in the United States is suffering from a multitude of health disparities. Many of these disparities are nutrition-related, as some of the biggest health issues that most disproportionately affect the Latinx population are obesity and diabetes. In order to treat these dietary-related health disparities, one must examine the complex aggregation of factors that work to influence one's specific dietary habits. Dietary habits are impacted by a series of individual, social and environmental factors. Moreover, in the case of Latinx nutrition, the level of acculturation, or cultural adjustment, plays a crucial role in determining dietary behavior. By utilizing the socio-ecological model of public health, these specific constructs can be carefully analyzed to determine their explicit impact on dietary behavior. After pinpointing the distinct function of each construct, the exact dietary-related needs and assets of a particular community or target population can be identified.

The East Dayton area as a whole is effected by incommensurate poverty and food insecurity, with the Latinx population possibly more affected as they are isolated and detached from various community resources. East End Community Services and Mission of Mary Farms, two non-profit organizations in the East Dayton area, have both expressed their inability to engage the Latinx population within their nutrition community programming. Therefore, the purpose of the proposed research includes two phases: First, by working with community partners, we will adopt both an asset and needs-based analysis to properly identify the specific nutritional needs of East Dayton's Latinx population.  The conclusions drawn from the assessment results will then be used in developing and implementing a culturally-tailored intervention to address these identified needs. In partnership with the community affiliates and target population, the development and implementation process for the intervention(s) will take place in the second phase of the research project, which will most likely occur in 2020.

## Health of the U.S. Latinx Population

As stated in the 2018 United States Census Bureau report, Latinx citizens account for over 18.1 percent of the United States population. By the year 2060, it is projected that the percentage of Latinx citizens living in the United States will rise significantly to approximately 28.6 percent (Velasco-Mondragon, et. al, 2016). As the largest ethnic minority in the United States, it is crucial that proper measures are taken in order to ensure adequate health care and resources for Latinx citizens. As a whole, the Latinx population suffers from a high rate of health disparities caused by certain social determinants. Social determinants of health exert health effects on individuals through allostatic load, "a phenomenon purported to cause chronic stress,

which elicits behavioral risk factors such as poor diet, sedentary behaviors and substance use, as well as biological processes such as circadian rhythm disruption, cytokine responses and inflammation." (pg. 31). These health inequalities occur mainly as a result of the difficulties created by their socioeconomic status, cultural background, employment status and foreign-born or undocumented status.

## The U.S. Latinx Population and Dietary-Related Health Disparities

In terms of nutritional health, many of the behavioral risk factors emanating from the allostatic load phenomenon are reflected in the nutritional decisions and diet culture of Latinx citizens. The Latinx population is disproportionately affected by a multitude of nutritional diseases, particularly obesity and diabetes. While obesity is an ever-growing issue and current epidemic for all groups within the United States, it has a significantly higher prevalence among Latinx citizens. According to the 2015 Census report, adult Latinx Americans were 1.2 times more likely to be obese than non-Latinx whites, and Latinx children being 1.8 times more likely than non-Latinx white children. The severe obesity epidemic has played a key role in the development of several other health issues amongst the Latinx population. Some of these health issues include metabolic syndrome (insulin resistance), non-alcoholic fatty liver disease (NAFLD), diabetes and cardiovascular disease (U.S. Minority Health, 2017). According to the National Health Interview Survey, Latinx citizens are almost *twice* as likely to be diagnosed with diabetes by a physician (NCHS, 2017). The Centers for Disease Control and Prevention (CDC) has strongly emphasized the notion that many of the leading causes of death for Latinx citizens, such as heart disease, diabetes, cancer and stroke, are direct consequences of obesity.

## East Dayton's Latinx Population

When examining Latinx health on a local level, specifically within the East Dayton region, U.S. Census reports indicate the Latinx population has been rapidly growing. From 2000 to 2017, Dayton's Latinx population grew from 2.4 to 6.2 percent. The most recent U.S. Census report found that in the East Dayton neighborhood, or

of those residing within the 45410-zip code, 29.3 percent of households reside below the poverty line and 7.1 percent of citizens are unemployed. When comparing this to U.S. Census data, the East Dayton neighborhood almost doubles both the national unemployment and poverty rates. While U.S. Census data specific to the Latinx population residing within this area is currently unavailable, it is plausible that the Latinx population is disproportionately affected by the current poverty crisis and aforementioned health disparities.

In spite of its current financial circumstances, the East Dayton neighborhood has continued to implement a variety of valuable and effective community efforts to address poverty and health issues. Several non-profit organizations within the East Dayton region are currently working to increase the quality of life within the community by providing the necessary resources and assets to its citizens. Some of these organizations include: St. Mary's Catholic Church, Target Dayton, Mission of Mary Farm and East End Community Center.

Collectively, East End Community Center and Mission of Mary Farms have made a substantial effort in combating the current issues of food and economic social justice within the East Dayton community. For example, East End has recently implemented the Food Access Resiliency Enterprise (FARE) initiative which focuses on increasing food affordability and access to East Dayton families. The FARE initiative provides various neighborhood development programs such as backyard and community gardens, advanced farmer training, mobile food pantries and organized farm markets. Apart from this, Mission of Mary Farms has worked to implement various food growing initiatives throughout the community. Some of these initiatives include: farm education visits, backyard gardening programs, community garden beds, teen employment programs and various workshops that focus on gardening, food preservation, cooking and sustainability.

Mission of Mary Farms and East End Community Services have both indicated their struggles with engaging the Latinx population in their community programming. Although East Dayton has a substantial Latinx population, Latinx involvement and participation within various community initiatives is considerably low. As East Dayton is a very ethnically diverse

neighborhood, it encompasses a multitude of cultural assets, specifically in the area of agriculture and food. By having community members share their unique and individualized assets with the general community, the East Dayton neighborhood would be exposed to a wider base of skill sets and resources—ultimately allowing the region to become increasingly more financially sound and healthy. As depicted in the second level of the socio-ecological model of public health, interpersonal relationships play a crucial role in shaping one's dietary behaviors. Inter-relational networks have great influence as they encompass the relationships and social interactions that a person has. By promoting community engagement, these organizations can work to boost healthy relationships among Latinx citizens and ultimately improve their overall health. Healthy relationships with friends and community members are crucial in the development and implementation of healthy dietary behaviors. New behaviors are much more easily adopted when an individual has reliable community resources and a proper support system.

## Dietary Behavior and Nutritional Assets of the Latinx Population

Typical foods in a Latino diet may include: beans, corn, peas, squash, tomatoes, rice, poultry, fish, cocoa, cactus and coffee. A traditional Latino diet is typically very high in fiber and is of high nutritional value. Research has consistently shown direct correlations between a traditional Latinx diet and lower mortality rates from chronic diseases (Cuy Castellanos, 2014). However, during the process of dietary acculturation and the transition to a more Westernized diet, many of the nutritional benefits of a typical Latinx diet are compromised (Velasco-Mondragon, et. al, 2016). When assimilating into U.S. culture, the Latinx diet is often negatively affected by a wide-variety of social, behavioral, environmental and dietary-related psychosocial factors. For example, it has been consistently found that Latinx citizens with a higher level of acculturation tend to consume a significantly higher amount of fatty and low-nutrient foods in comparison to Latinx citizens with a lower level of acculturation. Due to the limited availability of fresh produce and higher food prices, many Latinx citizens find it difficult to find fresh and affordable traditional foods within the United States. Additionally, the fast-paced and time-oriented culture of the United States prevents many Latinx citizens from following their typical meal schedule. Other common barriers that members of the Latinx population face during the dietary acculturation process can include lack of cooking skills, social interaction and a damaged home structure (Cuy Castellanos, Miller, 2017).

## Dietary Habits and the Socio-Ecological Model

In order to develop an effective solution to assuage the health inequalities affecting the Latinx population, one must appropriately assess



**Figure 1.** Adapted from: Bronfenbrenner, U. (1977). Toward an experimental ecology of human development. American Psychologist, 32(7), 513-531.

and evaluate the specific factors that impact one's dietary habits. Dietary interventions must be individualized and culturally-tailored as the dietary habits of an individual are influenced by an aggregation of these intricate factors. Furthermore, the overall degree of acculturation, or cultural adjustment, plays a critical role in the health inequalities experienced by an individual. The complexity of these factors can be clearly explained through the socio-ecological model of public health (see *Figure 1*).

While the model is comprised of five separate and distinct levels, each level overlaps with the other levels — signifying how a variety of factors affect the overall behavior of a community and environment. The first level is the "Individual" level, which includes knowledge, attitudes and skills related to the target behavior. The second level is the "Interpersonal" level, which examines how social networks, such as relationships with family and friends, can influence individual behaviors. Following this, the third level is the "Organizational" level, which analyzes how the rules and regulations of certain social institutions affect how efficiently public services are distributed to a specific individual or group. Next,

the fourth level, or "Community" level, explores how relationships among various institutions and organizations work to affect an individual's actions and behaviors. Lastly, the fifth level, or "Public Policy" level, measures the effects that local, state and national governments have on the allocation of resources to its citizens.

## Factors Affecting Latinx Dietary Habits

The socio-ecological model can help researchers to conceptualize factors effecting dietary behavior and to better understand their intricate connections. By dividing the various dietary-related factors into well-defined categories, the model provides a distinct explanation as to why an individual engages in certain dietary behaviors, which essentially allows for the adaption of more effective dietary interventions. In the case of Latinx nutrition, some of the factors examined include, but are not limited to: food insecurity, cultural feeding patterns, health inequalities and lack of preventative care, behavioral factors, social dietary norms

**Table 1.** Socio-Ecological Model Level Description

| Socio-Ecological Model Level | Description |
|---|---|
| 1. Individual | This level looks at how one's various traits and identities affects their overall health. It typically would examine genetics, lifestyle, diet, exercise patterns, education, level of acculturation, income, and legal status. This level provides the basis for the entire model. |
| 2. Interpersonal | This level examines one's interpersonal relationships and how it affects their overall health and dietary habits. Healthy relationships can encourage desirable eating patterns and habits and can promote a positive lifestyle. These relationships could range from being between friends, neighbors, family, or co-workers. The model examines how the nature of these relationships impacts one's eating patterns and nutritional choices. |
| 3. Organizational | This level examines the various organizations that have the biggest impact on Latinx health and dietary habits. The organizations with the biggest influence would most likely be schools, churches, and certain community engagement programs. These organizations have great influence as they can implement regulations that affect one's behavior and habits. |
| 4. Community | This level focuses on how Latinx nutrition is shaped by their interactions with communal organizations. It examines the overall customs of a particular environment and the effects it has on dietary habits. For example, it could look at Latinx participation in community programs and how it affects their overall nutritional health. |
| 5. Public Policy | This level includes state or national policies affecting Latinx nutrition as a whole. Examples of this could include FDA legislation, Low-Income food assistance regulations, and various regulations surrounding the issue of food insecurity. |

and targeted advertising for highly processed and low-nutrient foods (Velasco-Mondragon, et. al, 2016). To allow for a more straightforward conceptualization of the socio-ecological model in relation to Latinx nutrition, a chart representing the various dietary factors and their corresponding levels is included in *Table 1*.

Essentially, the main purpose of this research is to utilize both an asset and needs-based analysis to properly identify the specific nutritional needs of East Dayton's Latinx population. As previously mentioned, representatives from Mission of Mary and East End have indicated low involvement from the Latinx community within their programs. The organizations would like to determine how to empower the community in addressing nutrition-related issues as well as integrate the population's skills and knowledge of agriculture and food in their programs. By appropriately assessing the Latinx population's nutrition-related assets and needs, a well-informed intervention can be created that adequately addresses their precise nutrition needs and identifies how to better integrate the population's knowledge and skills into the organization's efforts.

In conducting the nutritional community assessment, partnerships will be made with select East Dayton community organizations who are specifically working to combat food insecurity and the current nutritional issues within the community. Some of these organizations include: East End Community Center, St. Mary's Catholic Church Latinx Outreach Ministry, El Pueblo and Mission of Mary Farms. Faculty and students at the University of Dayton have current working relationships with the aforementioned organizations. Information from the needs assessment will then be used to inform intervention development and implementation.

## Methodology

Due to the longer timetable and multi-step process needed for its effectiveness and lasting success, this research would require two separate phases (see *Figure 3*). The first phase would mainly consist of the engagement in a community nutrition assessment geared toward the precise identification of nutrition-related needs and assets. We will utilize the socio-ecological model to inform the assessment and data collection procedures (see *Figure 1*) in order to allow for a better understanding of the multiple levels of a community's social system and the various interactions that occur between the individual, environment and society. This phase would rely on the utilization of focus groups, semi-structured interviews and questionnaires to collect information. Data collection questionnaires will be adapted by prior research by Silva-Sanigorski and colleagues (2010). In the study, they utilized the socio-ecological model to inform data collection measure identification and development. Participants in data collection will include stakeholders and the target population. Furthermore, additional studies and secondary data collection methods will be implemented to garner other useful types of data.

After the completion of the community nutrition assessment, the collected data will be carefully interpreted in order to draw conclusions about the specific assets and needs important to the Latinx population living in East Dayton. The conclusions drawn from the results will then be used in developing an intervention to address these identified needs. The development and implementation process for the intervention will take place in the second phase of the research project, which will most likely occur in the summer of 2020.

While this research project has a lengthy timetable, and does not yield immediate results, it has the potential to generate extremely beneficial information and data concerning the Latinx community. Additionally, it would allow for increased Latinx participation within the East Dayton community, which could ultimately work to improve the current health and poverty crisis. By having Latinx citizens share their knowledge and individualized assets surrounding specific agriculture and food skillsets with the East Dayton community, they would not only expose others to new and diverse nutritional opportunities, but they would potentially allow themselves to have increased access to traditional nutritional resources. Through implementing specific community development programs targeted at the local Latinx population, East End Community Center and Mission of Mary Farms hope to encourage Latinx involvement within the East Dayton community. Predominantly, the main goal is to motivate Latinx citizens to utilize their expertise in traditional Latinx cooking and agricultural practices by sharing it with the surrounding East Dayton neighborhood through these specific community

development programs. The results of these specific community programs would be two-fold as they would expose East Dayton community members to innovative and diverse nutrition practices, while simultaneously aiding Latinx citizens in pursuing a healthy and nutritious diet by employing their cultural assets.

Overall, a multitude of social, behavioral, environmental and societal factors combine to play a major role in the dietary acculturation process of an individual. When designing interventions to confront the health disparities induced by the acculturation process, it is vital to take into consideration the diverse cultural factors that affect one's dietary behaviors. An intervention will only reduce health disparities and disease within the Latinx population if it targets multiple influencing factors.

## Acknowledgements

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# Investigating the Role of a p53 Mutation in Glioma Progression and Therapy Resistance in *Drosophila*: A Review

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## Abstract

Gliomas, which are brain tumors that arise from glial cells, are some of the most aggressive and lethal types of tumors. These brain tumors are difficult to treat because not enough information regarding the mutations present in these tumors exists. This project studies the effects of a *p53* mutation on *Drosophila* glioma progression and then testing to see if this results in resistance to current chemotherapy. *Drosophila* will be used as model organisms to mimic these processes. In order to do so, an effective *p53* knockdown will be made. In essence, this will effectively mimic a human brain tumor so the treatments tested and the data collected from this model can be applied to the current understanding of human gliomas. The effect of this specific mutation will be analyzed using florescent microscope imaging. In addition to studying just the *p53* mutation, additional mutations such as P13-Kinase, Arf, RTK and EGFR will be added. This will lead to an even more accurate glioma model because multiple mutations such as these are present in human tumors as well. These genetic crosses will be treated with Tyrosine Kinase Inhibitors, which are currently used to treat brain cancer patients. After receiving this treatment, the brains will be dissected, mounted on slides and imaged using a florescent microscope. This portion of the project will show whether or not this mutation plays a role in resistance to current therapy. The main goal of this endeavor is to investigate the numerous defects occurring at the cellular and biochemical level in gliomas, which will give insight into why these types of tumors are so difficult to treat. Data gathered from this project will lead to further inquiry into the role of *p53* mutations in gliomas and hopefully, to better outcomes for those affected by this type of cancer.

## Introduction

Gliomas arise from glial cells which comprise the connective tissue within the brain. The glia function to provide support and protection to neurons in the brain. However, specialized types of glia such as astrocytes and oligodendrocytes serve more specialized roles such as controlling neurotransmitter levels and producing myelin, respectively [13]. Through a series of mutations, previously healthy glia can become cancerous and form a tumor. Even if the tumor is completely removed via surgery, the chances of the tumor recurring in the same location as before are high. This is because some residual cells may be left behind, in an effort to leave as much healthy brain tissue as undisturbed as possible, furthermore, larger tumors commonly breakdown the blood-brain barrier [14]. Gliomas make up 81% of all malignant brain tumors. They also occur in both adults and children.
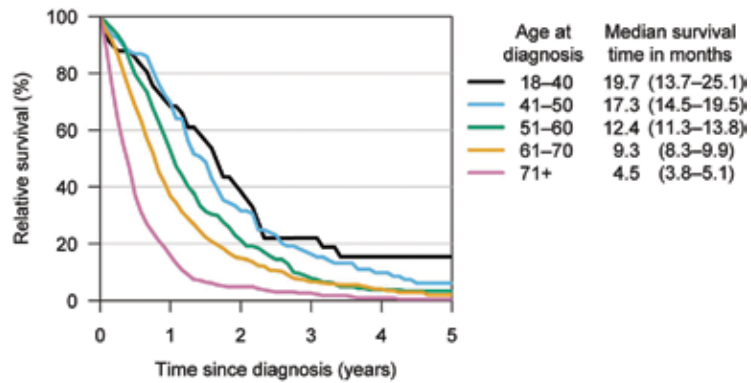
**Figure 1.** Median survival times and relative survival rates for different glioblastoma patient age groups. Brain cancer survival has improved – but not much for elderly. Courtesy of *Medical Xpress*, University of Helsinki, 2018.

Although there are many different types of gliomas, one in particular, Glioblastoma multiforme (GBM), is one of the most lethal forms of brain cancer. The survival rates across all age ranges for GBM are extremely low, with the median survival at the time of diagnosis being slightly under two years. As seen in *Figure 1*, compared to other types of malignant brain tumors, the median survival time post-diagnosis for GBM patients is astoundingly low. Although younger patients tend to fare slightly better than those in the older age ranges, it is not likely that these patients will still be alive five years after diagnosis, even after receiving proper treatment. The common course of treatment for this disease includes surgery to remove the tumor, followed by chemotherapy and radiation therapy. However, as mentioned earlier, even if the patient survives these grueling treatments and achieves remission, the odds of the tumor coming back, oftentimes in the same location, are very high. Once the cancer has returned, it is usually more aggressive and resistant to the previous therapies.

GBM is highly lethal due to the lack of information regarding the cellular and biochemical defects present in the tumor. If more information regarding these mutations existed, more targeted therapies could be used to combat this disease, which is often resistant to therapy. However, with treatments that can act on pathways known to contribute to tumor progression and therapy resistance, these survival rates will likely improve.

## Known Contributors to Therapy Resistance

### MESENCHYMAL VS. PRONEURAL STEM CELLS

The type of stem cell that the glioma arises from plays a role in the tumor's response to therapy. The stem cell can be either proneural or mesenchymal. Certain signaling events in these stem cells are known to be linked to various tumor subtypes. These two stem cell types preferentially activate different pathways, therefore contributing to the difference in therapy response [11]. Mesenchymal GBM are often more aggressive than Proneural GBM, causing tumors with this stem cell type to respond poorly to current therapies. Specifically, Mesenchymal GBM are significantly more resistant to radiation treatments.

### IDH MUTANT VS IDH WILDTYPE

Mutations that occur in isocitrate dehydrogenase (IDH) are early events in tumorigenesis. These mutations cause the enzymes in the cell to be changed, so an oncometabolite is produced instead of the cofactor NADPH [1]. This type of mutation has been found in other types of cancer as well, including some forms of leukemia and therapies that target this mutation in hematologic cancers have shown some promise [2]. But, these therapies are not as effective when used to treat gliomas.

## Mutations of Interest:

### P53

The *p53* mutation will give insight into a glioma's wide range of properties. Not only is this specific gene known to be a tumor suppressor but also has many other vital functions, such as modulating the cell cycle [3]. *Figure 2* represents the many functions of the non-mutated *p53* gene which result from the input of various stresses. Certain *p53* mutations are thought to be early events in the process of tumorigenesis [16]. Loss of *p53* can cause an increased risk for gliomas to develop when they occur as germline mutations and often occur with the deletion of the chromosome 17p [16]. *p53* mutations are most often seen in patients with high-grade gliomas rather than those with low-grade tumors, which suggests its

possible usefulness in predicting prognoses [7]. Other mutations are also present in conjunction with the *p53* mutation in many gliomas and must be considered in order to formulate a proper representation of a human glioma.
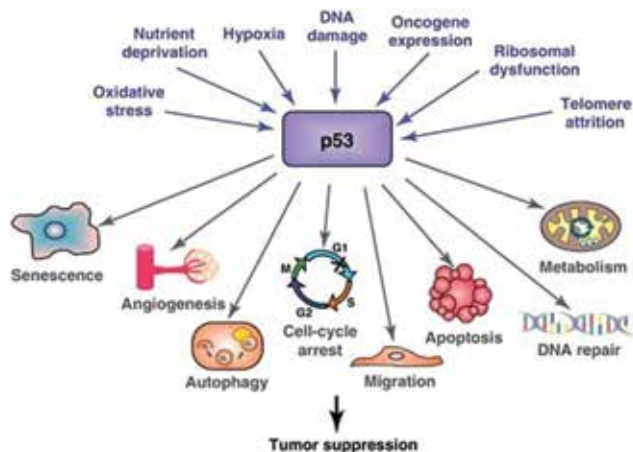


**Figure 2.** The p53 tumor suppressor. Courtesy of Bieging and Attardi, et al. Trends in cell biology. *TRENDS in Biology*, 2012.

## E2F

E2F genes encode transcription factors that are responsible for modulating the cell cycle. The transcription factors are known to play a role during the transition from the G1 to the S phase, however, they are thought to modulate other phases of the cycle as well. These E2F genes can also work as tumor suppressors and when mutations occur, this function no longer works correctly. Furthermore, E2F makes proteins that mediate *p53*-independent/dependent apoptosis [8].

*Figure 4* represents the many benefits of using fruit flies to investigate human genetics and highlights the steps necessary to create a proper fly model. The combination of their quick repopulation time, ability to ingest cancer drugs in vivo and the similarities they share with humans in regards to their molecular pathways make them a practical tool to study specific mutations in human gliomas [18,8]. Additionally, fruit fly models have many medicinal applications because they allow for human diseases to be studied at the genetic level in order to develop better therapies. This project will employ the widely recognized method of creating gliomas in *Drosophila* through the use of Mendelian genetics [8]. The process will involve creating crosses of flies which downregulate a certain tumor suppressor gene e.g., Pten and over-activate
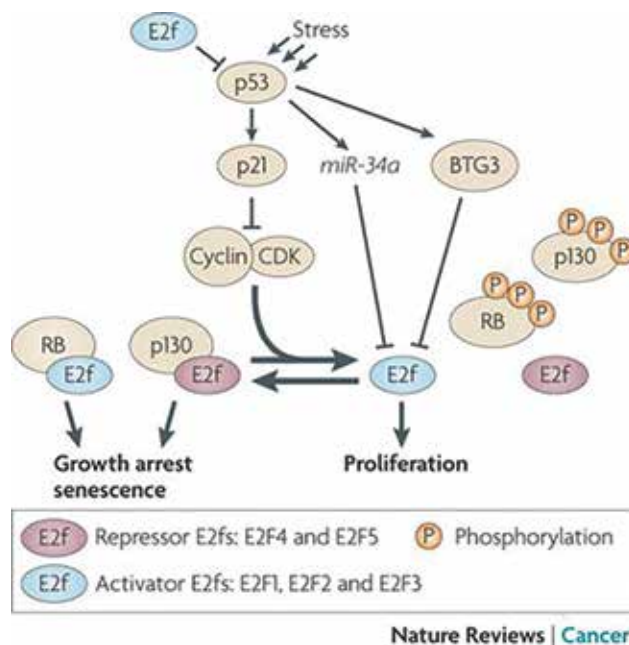


**Figure 3.** *Drosophila melanogaster* glioma model — p53 and E2F: Partners in life and death. Courtesy of Polager, S. and Ginsburg, D. *Nature Reviews Cancer*, 2009.

an oncogene e.g., RasV12. Even though this model will mimic human gliomas, it will not fully express all the mutations found in them. Therefore, by creating crosses with additional mutations known to be present in human brain tumors, this model will give a clearer picture of human gliomas.

## PTEN Pathway

Pten is a phosphatase and Tensin homolog that functions as a tumor suppressor. Mutations in Pten are known to occur in nearly every type of cancer. In its non-mutated form, Pten plays a role in cell cycle progression, apoptosis and cell proliferation in addition to many other important cellular processes [9]. Pten also inhibits the PI3K/Akt pathway[17]. In *Figure 4*, the activation of RTK results in downstream signaling of Pten. When loss of Pten activates the PI3K pathway, tumors are more resistant to therapy [9]. The reason for incorporating a downregulation of Pten into the tumor model is due to its prevalence in gliomas. In fact, studies have shown that deficiencies in Pten are associated with lower median survival periods for patients with GBM [19]. Therefore, this mutation is pertinent to include in glioma models as well as test with various drugs in order to target these defects.
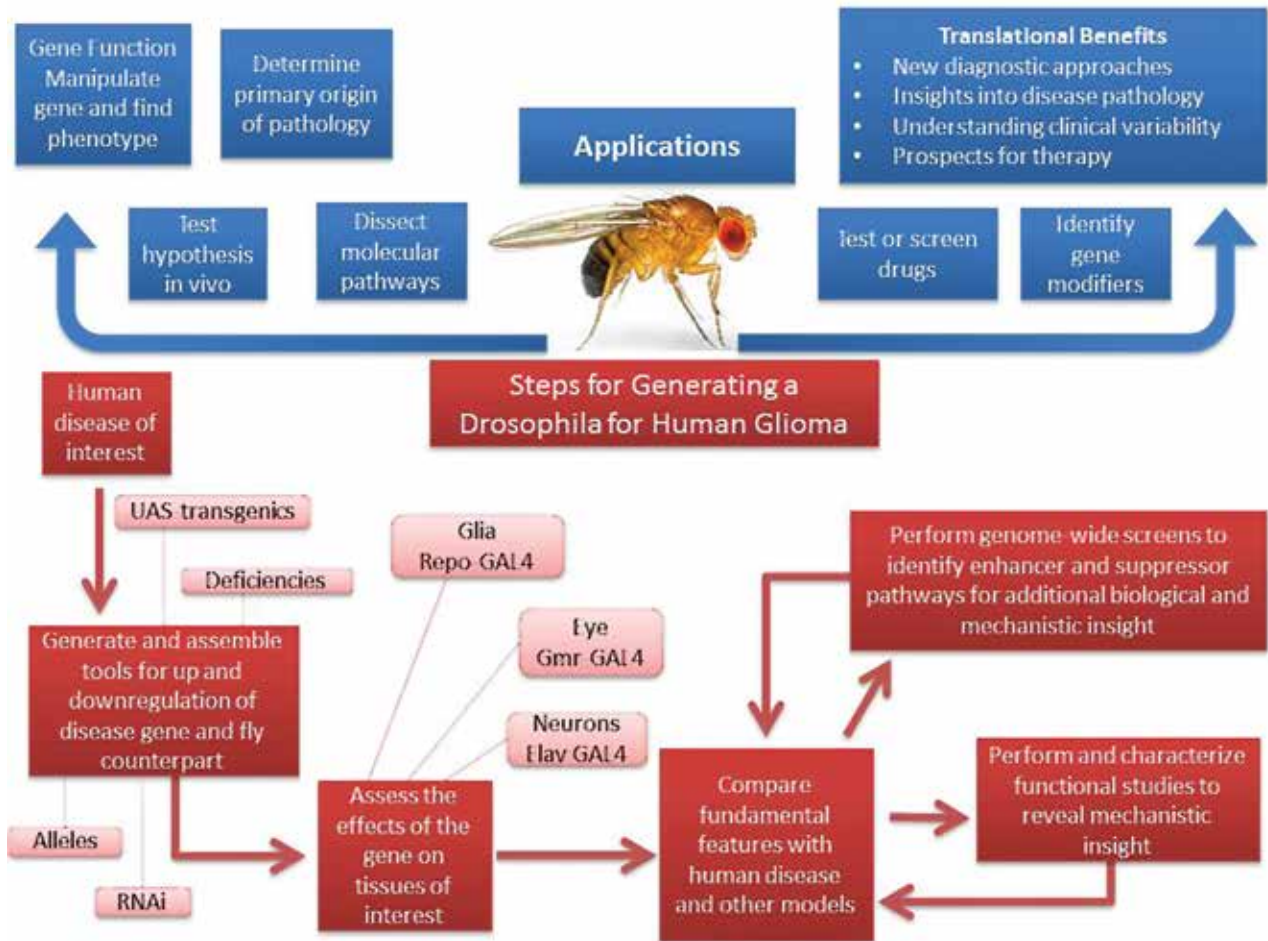
**Figure 4.** Advantages of *Drosophila* model in the study of human diseases. (Modified) courtesy of Monique van der Voet, et al., Advantages and application of *Drosophila* as a disease model. *Science Direct*, 2014; and Leeanne McGurke, et al., Steps for generating and characterizing a *Drosophila* model for a human neurodegenerative disease. *Genetics Society of America*, 2015.

Ras is an oncogene found in numerous types of cancers one of which being GBM. Ras can be activated and deactivated by binding to GTP or GDP [10]. Certain growth factors, namely receptor tyrosine kinases (RTKs), regulate Ras activity which in turn, causes Ras to activate RAF. This activation leads to the phosphorylation of many kinases, specifically MAPK, allowing Ras to regulate cell activities downstream [10]. Disturbances within the Ras/MAPK pathway contribute to oncogenesis.

Incorporation of this oncogene into the glioma model is pertinent to this study due to its prevalence in human GBM. The overexpression of Ras has been identified in numerous cases of high-grade astrocytomas and GBM [5]. Studies in which Ras binding has been inhibited resulted in the augmentation of apoptosis and tumor regression [17].

Although these mutations will be used to induce the tumor, other mutations will be added as this project progresses. For example, an epidermal growth factor receptor (EGFR) mutation will be used. EGFR is a tyrosine kinase and mutations causing it to undertake oncogenic properties are cited in many other cancers, including GBM. However, therapies that target the EGFR mutation in other cancer types are not nearly as effective when used for GBM patients [15]. Another such mutation to be considered is an arf mutation, which is a modulator of *p53* activity [12]. The inactivated or mutated form of arf has been found in both high and low-grade gliomas [15]. Since human gliomas have a wide range of mutations, multiple mutations must be added in order to achieve an effective model.
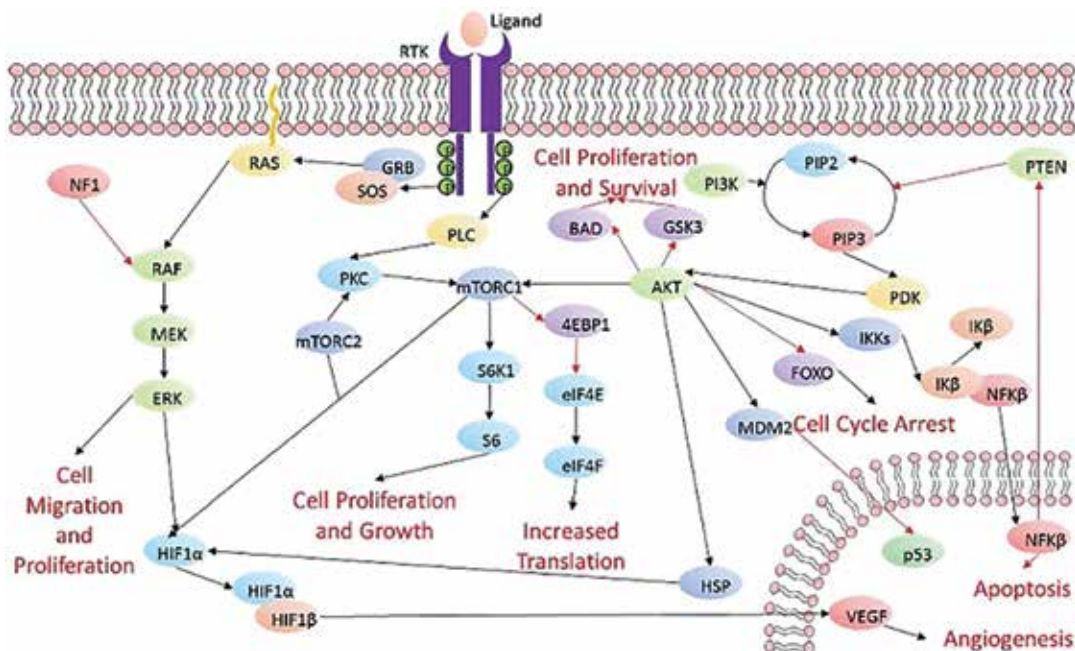
**Figure 5.** RasV12 Pathway; RTK activation and downstream signaling. Courtesy of Pearson, J. and Regad, T. Targeting cellular pathways in glioblastoma multiforme. *Signal Transduction and Targeted Therapy*, 2017.

## Testing for Drug Resistance

In order to test if the mutations contribute to drug resistance, they will be tested with a multitude of chemicals used for chemotherapy treatments. This will be accomplished by adding the drugs to the food, in vivo when the larvae are three days old. Then, their brains will be mounted when they are five and six days old, during the third instar stage. The brains will then be imaged with a fluorescent microscope and compared to the controls. This will give insight into what kind of role these mutations play in drug resistance, both independently and in conjunction with the aforementioned mutations.
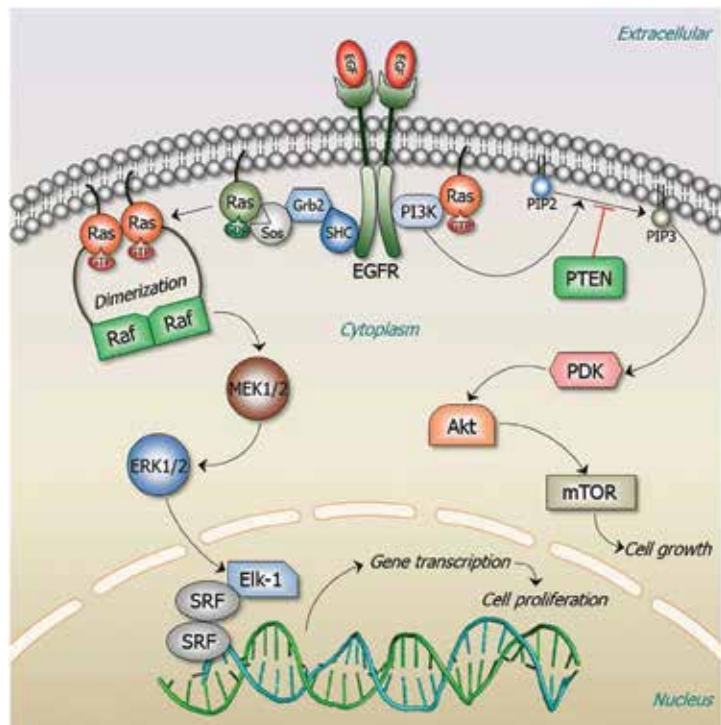


**Figure 6.** Ras Pathway. Courtesy of Nussinov, R., et al. The structural basis for cancer treatment decisions. *Oncotarget*, 2014.

## Tyrosine Kinase Inhibitors

Tyrosine kinases are enzymes that mediate the signaling cascade. These pathways prevent unregulated proliferation. mTOR (non receptor tyrosine kinase), which is a downstream target of the PI3K pathway causes cell proliferation in GBM. Tyrosine kinase inhibitors decrease tyrosine kinase phosphorylation by competing with ATP's binding site. Certain Tyrosine Kinase Inhibitors such as Gleevec (Imatinib) and Herceptin (Trastuzumab) have made a dramatic impact on survival rates for patient suffering from leukemia and breast cancer respectively [12]. In terms of GBM, this class of drugs is highly selective compared to previously used

therapies. However, many tumors are multi-drug resistant and therefore are not suppressed by this treatment alone.

## Conclusion

Overall, due to the lack of knowledge regarding the role of specific mutations in gliomas, treatments are minimally effective, causing this disease to have an extremely high mortality rate. This project aims to bridge this gap in information by studying the *p53* mutation and mutations within the E2F family of genes along with other mutations known to contribute to tumor progression and therapy resistance. By looking into the effects of these mutations as they occur by themselves as well as with many others, we will be able to gain a better understanding of glioma tumorigenesis. Furthermore, treating these brains with Tyrosine Kinase Inhibitors will provide insight into their role specific to therapy resistance. Information gained from this project will hopefully lead to more targeted therapies for glioma patients. These therapies will act on the pathways known to contribute to tumor progression and therapy resistance, therefore efficiently destroying the tumor and salvaging healthy tissue. This project aims to better the prognosis for people affected by this devastating disease.

## Acknowledgements

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# On the Behavioral and Neuromolecular Effects of Adolescent Social Defeat Stress in Rats and Mice

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## Overview

Within the past century, medical techniques and procedures have evolved at an exponential rate, greatly increasing life expectancies and the quality of life for billions of people. Despite these advancements, depression, anxiety and other stress-related disorders still severely affect millions of people around the globe. From 2005 to 2015, major depression rates have increased by 18 percent and, in the US alone, a staggering 33 percent [1]. Strikingly, nearly one in four adolescents suffer from a mental health disorder which can result in detrimental impairments throughout their lives [13]. It has long been known that drastic developmental changes occur in the adolescent brain making teenagers more susceptible to emotional and physical stress [28], the most prominent being social and physical defeat from stronger peers (i.e., bullying). Strikingly, it has been reported that nearly 50 percent of adolescents experience some form of bullying [19,20]. Adolescent rodent models have been widely implemented to model the behavioral and neuromolecular effects of social defeat stress, yet very few studies have been dedicated to deciphering the neurochemical changes that occur in the adolescent brain. In this current review, we will discuss the behavioral and neurobiological findings of studies that have used the resident-intruder paradigm to probe the effects of social defeat in adolescent mice and rats.

## The Resident-Intruder Paradigm

In order to effectively model bullying in adolescents and the associated social defeat stress, the resident-intruder paradigm (*Figure 1*) is used. This paradigm has been used by numerous neuroscience laboratories worldwide and has been shown to reliably and effectively induce social defeat stress in rodents [3]. The
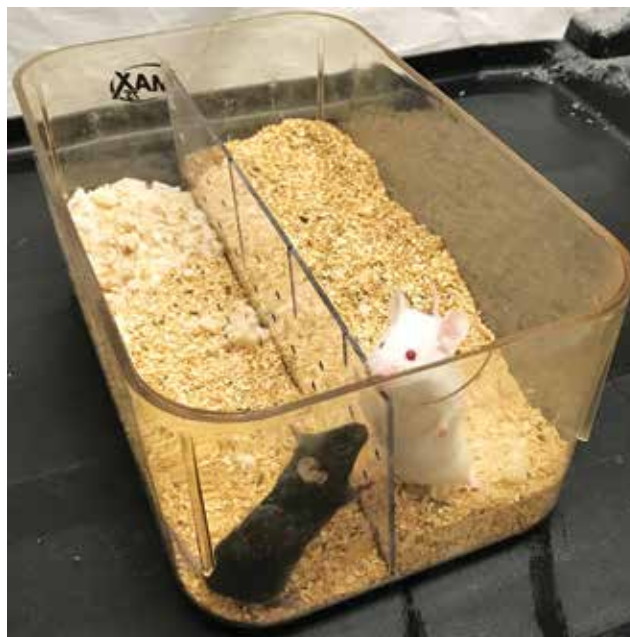


**Figure 1.** The resident-intruder paradigm has been shown to reliably induce chronic social defeat stress. An adolescent C57BL/6J mouse on the left interacting with an adult male CD-1 mouse across a perforated Plexiglass wall. Photo courtesy of Pitychoutis Laboratory, 2019.

resident-intruder test paradigm is typically conducted in cages divided into two compartments by either a perforated plexiglass wall or wire mesh divider (*Figure 1*). The divider ensures retainment of the rodents' optical, olfactory, and auditory senses while prohibiting aversive contact [3]. Male retired breeders reside on one side of the cage and serve as aggressive "bullies" for the intruder rodents [2,3,5]. An intruder rodent is placed in the same compartment with the resident mouse and left to interact for 5 to 10 minutes [3,5]. After this session, the intruder is transferred to the adjacent compartment for 24h. The next day, the intruder rodent is moved to a novel resident and the paradigm is typically repeated for ten consecutive days [3].

## Behavioral Effects of Social Defeat Stress in Adolescent Rodents

The behavioral effects of social defeat induced in adolescent rodents can be assessed either immediately following the stress regimen or in adulthood. The majority of studies have assessed the protracted effects of stress exposure, and relatively fewer studies have focused on the early aversive effects of social defeat. Herein, we will discuss important findings pertaining to both the early and protracted effects of adolescent social defeat stress on different aspects of behavior, namely: anxiety, depressive-like behavior and learning and memory.

## Effects of Adolescent Social Defeat on Anxiety-Like Behavior

Social avoidance is believed to be a common phenotype of anxiety that is aggravated by stressful situations. Social avoidance is assessed using social interaction tests in which the time individual rodents spend interacting with a novel conspecific is recorded and blindly scored by a trained observer (*Figure 2*). Immediately following the resident-intruder paradigm, it has been shown that defeated rodents exhibit elevated levels of social avoidance when compared to control rodents that have not undergone the stress procedure [5,6,8,29,30]. The effects of this social defeat stress during adolescence has also been evaluated in adult rodents and numerous studies have reported that adult rodents exposed to social defeat during adolescence still exhibit higher



**Figure 2.** Social Avoidance test: a C57Bl/6J mouse avoids interaction with a novel social stimulus (i.e., a mouse placed in a wire cage in the top center wall of an open field arena. Photo courtesy of Pitychoutis Laboratory, 2019.

levels of social avoidance, as compared to their unstressed counterparts [21,24,25]. These results indicate that social defeat stress during adolescence induces immediate and long-lasting social anxiety in rodents.

Rodents are typically very active when introduced into a novel environment, such as an open field (OF) arena. The OF test is widely used to assess the effects of stressful manipulations



**Figure 3.** Anxiety-like behavior in the OFT is expressed in reduced locomotor activity and avoidance of the center of the OF arena. Photo courtesy of Pitychoutis Laboratory, 2019.

on spontaneous locomotor activity and anxiety-like behavior in rodents. Anxiety is typically expressed in the OF test as an overall reduction in exploratory activity, as well as direct avoidance of the center of the OF (*Figure 3*). Relatively few studies have employed the OFT to assess the immediate effects of social defeat stress on anxiety-like symptomology, and the existing literature offers conflicting results. It has been reported that defeated rodents display drastically reduced locomotor activity, as well as increased avoidance of the center of the OF [29]. However, another study reported no differences in locomotor activity and area preference upon social defeat exposure [7]. Even fewer studies have employed the OF test when investigating the long-lasting effects of social defeat stress in adolescent rodents. However, it has been reported that social defeat stress during adolescence may enhance risk-taking behavior of defeated mice, as evidenced by increased locomotor activity and time spent in the center of the OF [9].

Similar to the OFT, the elevated plus maze (EPM) evaluates anxiety-like symptomology in rodents based on their natural aversion to open spaces (*Figure 4*). In this test, rodents are able to freely move through a plus maze in which two arms are left open and the other two arms are enclosed. Anxiety-like behavior is exhibited by significantly increased time spent in the enclosed arms of the maze (*Figure 4*). While it has been



**Figure 5.** Immobile behavior indicates learned helplessness and behavioral despair in rodents. Photo courtesy of Pitychoutis Laboratory, 2019.

reported that immediately following social defeat stress, rodents exhibit a significantly increased preference for the enclosed arms of the EPM [30], another study has also reported no statistical difference between defeated rodents and their unstressed counterparts [7]. Current literature concerning the long-lasting effects of social defeat stress during adolescence is also conflicted. It has been reported that defeated rodents spend more time in the enclosed arms of the EPM [21], the same amount of time [25], and less time than their control rodent counterparts [9].

## Effects of Adolescent Social Defeat on Depressive-Like Behavior

The Forced Swim Test (FST) has been widely used in evaluating behavioral despair within rodents (*Figure 5*). In this test, a glass beaker or tube is filled with enough water (23-25°C) to prevent the rodent's tail from touching the bottom and to prevent the rodent from climbing out [14]. The rodent is placed in the beaker or tube and its behavior is observed. Periods of increased immobility (i.e., passive floating) are indicative of learned helplessness and depressive-like behavior that is effectively reduced upon acute



**Figure 4.** The EPM assess rodent anxiogenic behavior based on their natural aversion of open spaces. Photo courtesy of Pitychoutis Laboratory, 2019.

antidepressant drug treatment [31]. Immediately following social defeat stress during adolescence, defeated rodents consistently exhibit significantly increased periods of immobility [7,8,29,30]. Unfortunately, the protracted effects of social defeat stress during adolescence are less understood. However, it has been reported that adult mice defeated during adolescence may also exhibit increased periods of immobility in the FST [21].

Anhedonia, or the lack of finding pleasure in activities that would normally bring pleasure, is a core symptom of depression and the sucrose preference test is a reliable and effective way of assessing establishment anhedonia in rodents [32,38] (*Figure 6*). In the sucrose preference test (SPT), rodents are able to select between a sweet sucrose solution and normal water [32]. Several studies have utilized the SPT as an indicator for the establishment of anhedonia. It has been reported that social defeat stress during adolescence exerts immediate anhedonic effects in the SPT, evidenced by loss of preference for the sweet sucrose solution in defeated rodents [7,30]. Conversely, it has also been reported that this stress has no immediate or protracted effects on rodents [22,33]. Concomitant to anhedonia, changes in appetite and weight loss is another

depressive phenotype that is common among stressed rodents [38]. Specifically, immediately following social defeat stress during adolescence, defeated rodents have been reported to exhibit significantly reduced body weights when compared to their unstressed control counterparts [8,30]. However, one study reported contradictory results, showing that there were no significant differences in weight between the defeated and control groups [5].

As previously stated, drastic developmental changes occur in the brain during adolescence, which increases teenagers' susceptibility to stress and is implicated in the development of cognitive deficits [34]. Numerous behavioral tests can be employed by investigators to assess cognitive function in rodents, including the Attentional Set-Shifting Task (AST), Delayed Win-Shift Task, Delayed T-Maze, and Operant Strategy-Shifting Task (OSST). By utilizing the AST, it has been reported that rodents defeated during adolescence displayed protracted, rather than immediate, cognitive deficits [4,6]. These findings are shared by other studies that utilized the Delayed Win-Shift Task [22], Delayed T-Maze [22], as well as the OSST [34]. These findings suggest that social defeat stress during adolescence has lasting effects on the developing prefrontal cortex, which results in a delayed and long-lasting impairment of cognitive function [34].



**Figure 6.** A decreased preference for the sweet sucrose solution indicates anhedonia. Photo courtesy of Pitychoutis Laboratory, 2019.

## Neuromolecular Effects of Social Defeat Stress

The immediate and delayed neurochemical underpinnings of social defeat stress during adolescence largely remain elusive on account of the relatively few existing studies and the contention between their reported findings. However, there are several studies which detail both the acute and protracted effects of this stress regimen on monoaminergic systems (i.e., dopaminergic; DAergic, noradrenergic; NAergic, serotonergic; 5-HTergic) as well as the amino acid glutamate.

Stress-induced effects on the serotonergic system have been widely studied in rodents subjected to social defeat stress in adulthood [35,36]. Despite this, the immediate and delayed neurochemical effects of social defeat during adolescence largely remain unknown. However,

one study found that, immediately following social defeat, levels of 5-HT were found significantly increased in the prefrontal cortex (PFC), the nucleus accumbens (NAc), and the amygdala (AMY) [5]. Another study reported an increase in 5-HT in the ventral dentate gyrus (vDG) region of the hippocampus (HIPP) in adult rodents [9].

Similar to the serotonergic system, the noradrenergic system is also believed to play a crucial role in the neurobiological response to social defeat stress [37]. Despite this, the existing literature concerning social defeat stress in adolescent rodents and its acute and chronic effects are extremely limited. One study utilizing high-performance liquid chromatography (HPLC) reported that immediately following social defeat stress in mice, there were no alterations in the noradrenergic system in the PFC, NAc, HIPP and AMY [5]. However, in a protracted study, the investigators reported that levels of NA increased in the vDG and decreased in the dorsal raphe nucleus of defeated rats [9].

The dopaminergic system has only recently been considered in the physiological response to social defeat stress [35]. In a study investigating the immediate effects of social defeat in adolescent mice, it was found that levels of DA significantly increased in the NAc, the HIPP, the AMY [5], and the PFC [17]. Moreover, it has been reported that defeated adolescent rats display decreased levels of DA in mPFC [9,17] and the striatum (STR) when assessed in adulthood [23].

Only recently has the glutamatergic system been believed to play a role in the neurochemical response to social defeat stress [18]. It has been reported that, in adult rats, there are increases in glutamate levels in the infralimbic cortex and the AMY, as well as decreases in glutamate levels in the CA3 region of the HIPP [18].

The immediate and protracted effects of social defeat stress during adolescence on gene and protein expression have been recently investigated. It has been shown that brain-derived neurotrophic factor (BDNF), a neurotrophic protein that nourishes neurons, is extremely sensitive to social defeat stress during adolescence. This protein is believed to play a crucial role in the neurobiology of depression and in responsiveness to antidepressant drugs [4], as well as in neural development and cognitive flexibility [39]. Specifically in adulthood, there was drastic downregulation of BDNF expression in the mPFC [4]. Another study which investigated the acute and chronic effects of stress, noted a biphasic effect in BDNF expression as BDNF levels increase immediately following stress exposure but were found decreased in adulthood [39]. C-fos, a proto-oncogene, can be used in assessing the neuronal activity by utilizing immunohistochemical techniques [41]. One study reported immediate increases in mPFC c-fos expression during adolescence, yet these levels were found to decrease in adulthood [34]. Specifically, they found a positive correlation between mPFC c-fos positive cells and cognitive flexibility indicating that social defeat stress during adolescence induces protracted cognitive impairment [34].

Another study looked into the immediate effects of social defeat stress on the regulation of transcription factor MAX on account on its increased expression, activity and vulnerability during adolescence [7]. By using immunohistochemistry and immunofluorescence on adolescent mice, it was found that MAX nuclear immunoreactivity was elevated in the HIPP and decreased in the STR; no alterations were found in the PFC [7].

The adolescent brain is extremely susceptible to stress, as indicated by extensive structural changes in dendritic spine morphology observed in stress-sensitive brain regions, such as the HIPP [40]. Indeed, one study utilized Golgi-Cox staining to assess spine morphology immediately following social defeat during adolescence, and defeated mice displayed a significant decrease in the number of stubby spines and an increase in the number of long-thin spines in the CA1 region of the HIPP [8]. Taken together, social defeat stress during adolescence induces morphological alterations in the HIPP which may play a role in the development of anxiety and depressive-like behavior [8].

Last but not least, the hypothalamus-pituitary-adrenal (HPA) axis plays an important role in the neuroendocrine response to stress. As a result, numerous studies have looked into the immediate and long-lasting effects of social defeat stress during adolescence on blood plasma corticosterone levels. Immediately following social defeat stress, multiple studies report defeated mice having significantly increased blood levels of corticosterone [8,30]. However, one study in mice reported that there were no immediate alterations in blood plasma corticosterone levels [7]. Similar to the immediate

results of social defeat stress during adolescence, one study reported that blood corticosterone levels remained elevated in defeated rats into adulthood [9].

## Conclusion

Social defeat from strong peers (i.e., bullying) is an increasingly prevalent and debilitating problem in society today and it has extremely drastic immediate and protractive ramifications for its victims. By using the resident-intruder paradigm of social defeat stress in adolescent rodents to model bullying in teenagers, numerous studies have found that this regimen induces both immediate and long-lasting alterations in rodent behavior, cognition, neurochemistry and gene expression in the brain.

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# A Literature Review of the Fields of Mathematics and Music

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## Abstract

We provide a literature review of the field of mathematics and music. We start with the basic connections between mathematics and music found within the physics of sound, the concepts of notes, intervals and scales, various tuning systems and music notation. Mathematical structures from, e.g., group theory are also found in the various musical transformations that are used within a musical composition. Some interesting concepts within the field also include the topics of Euclidean rhythms, atonal composition and change-ringing. This work is an exploration of the field of mathematics and music starting from basic to more complex in terms of mathematical structures.

## Introduction

Mathematics and music are intrinsically linked with one another. For example, rhythms are simply periodic numerical patterns. A relatively large field of resarch and literature exits that explores the relationship between mathematics and music, including an active academic journal, the *Journal of Mathematics and Music*. However, before exploring some of the various connections that exist between mathematics and music, we provide an overview of some important fundamental mathematical concepts.

## Mathematics Overview

In order to understand the connections that exist between mathematics and music, we must first explore several fundamental mathematical subjects.

A *relation* associates members of one set, say $X$ with members of another set, say $Y$, where a set is a collection of objects, known as elements [1]. These *elements* can also be sets themselves, designated as *subsets* of the original set. A *function* is a relation that *uniquely* associates elements of $X$ with elements of $Y$ [1]. So, each element of $X$ is associated with one and only one element of $Y$, although elements of $Y$ may be associated with multiple elements of $X$.

In essence, a function can be thought of as taking the elements of the first set $X$ and transforming them into the elements of the second set $Y$. A function is then a subset of $X{\times}Y$, where $X{\times}Y$ is a set of pairs of elements, one from $X$ and one from $Y$. To be specific, let $x{\in}X$ and $y{\in}Y$. If $x$ is related to $y$ by some function f, then we say that the ordered pair $(x,y) \in f$, oftentimes denoted as $xfy$. Note that since f is a set of ordered pairs, we are able to have $(x,y ) \in f$ without any problems.

Many types of relations, of which a function is a type, exist in mathematics. For example, an *equivalence relation*, $R$, on a set $X$ is a subset of the larger set $X{\times}X$, the set of ordered pairs composed of elements of $X$, satisfying the properties of reflexivity, symmetry and transitivity [7]. Note that $R$ is only a set of ordered pairs, and not necessarily a function. $R$ is

reflexive if for all $a \in X$, we have that $aRa$. $R$ is symmetric if for all $a,b \in X$, aRb forces $bRa$. Lastly, $R$ is transitive if for all $a,b,c \in X$, if $aRb$ and $bRc$, then $aRc$. Notice that $R$ behaves as if the two elements it relates are equivalent.

Let $X$ be a set of elements. An equivalence class is a subset of the form $[x] = \{y \in X : xRy\}$, where $R$ is an equivalence relation [7].

A function can behave in a repetitive manner. A function $f$ is said to be periodic with period $p$ if and only if for all $x$ in the domain of $f$, we have that $f(x+p) = f(x)$, where $p \in \mathbb{R}$ [1].

Among the periodic functions that exist, the most notable within music is that of the sine function. Imagine a point traveling along the perimeter of a circle. As the point goes along the circle, a line, known as the *hypotenuse*, can be drawn from the center of the circle to the point. Additionally, the point has certain horizontal and vertical components, which can then be drawn as a horizontal, known as the *adjacent*, and vertical, known as the *opposite*, line from the axes of a coordinate plane superimposed onto the circle, with the center of the circle at the origin. These three lines then form a right triangle, with an angle $\theta$ between the horizontal line and the hypotenuse. The sine function is then defined as $\sin \theta = {}^{\text{opposite}}/_{\text{adjacent}}$.

When graphed, the function produces a periodic wave-like pattern.

A finite *group G* is a finite set of elements in combination with a binary function, or *operation*, usually denoted as *, with certain properties [1]. This operation is often notated as multiplication and acts between two elements of $G$. The properties that the group and operation must possess are closure, associativity, identity and inverse.

- *Closure* is defined as the property wherein if $a,b \in G$, then the operation performed on $a$ and $b$, usually written as $a * b$, or equivalently, $ab$, is also in $G$.

- *Associativity* is a property such that for all $a,b,c \in G$, we have that $(a ' b) * c = a * (b * c)$.

- Identity means that there exists an identity element $I \in G$ such that for all $a \in G$, we have that $I * a = a * I = a$.

- Lastly, inverse means that for each $a \in G$ there exists a $b \in G$ such that $a * b = b * a = I$, where I is the identity of $G$. We say that $b = a^{-1}$.

Consider the ways in which a shape can be changed in such a way that the shape remains the same, but the orientation of the shape changes. These operations consist of rotations, reflections, and inversions. A *symmetry group* is a group of symmetry-preserving operations, i.e. operations that only change the orientation of an object. More formally, a symmetry group is the set of all possible symmetries on some set, i.e., the set of all possible sequences of elements in some set [1].

The *dihedral group*, $D_n$, is defined to be the symmetry group of an n-sided regular polygon, where $n \in N$ [1].

Let G be an arbitrary group with operation *, let $X$ be a set and let $x \in X$. We define the left group action as the map:

$$G \times X \to X$$

$$(g,x) \mapsto g.x$$

where the external law, denoted . , satisfies the following properties:

$$\forall x \in X, I.x = x$$

$$\forall (g,g') \in G^2, \forall x \in X, g'.(g.x) = (g * g').x$$

We then say that $G$ operates (on the left) on the set $X$. This is a left group action and a right group action can be defined similarly.

Given a left group action, the *orbit* of $x$, denoted $G(x)$, is defined as the subset of $X$:

$$G(x) = \{g.x \in X : g \in G\}.$$

Note that the orbit can be defined similarly for a right group action [1].

We now move on to a fundamental overview of the qualities and characteristics of sound.

## An Overview of Sound

If you were to read these words aloud to yourself, you would hear your own voice. What is it that your ears are actually registering when they hear your voice? Your ear is detecting the changes in air pressure caused by the air from your lungs passing through your vocal chords and creating vibrations.

These changes in air pressure manifest themselves as *waves*. A wave is an organized travelling disturbance in a medium, according to David J. Benson in *Music a Mathematical Offering* [1]. Usually, sound manifests itself in the form of *longitudinal waves*, which are changes in air pressure parallel to the propagation or movement of the wave. It should be noted that in solids, sound may also travel as a transverse wave, which is an orthogonal displacement of the medium with respect to the propagation of the wave.

It can then be said that sound is simply the occurrence of pressure waves in a medium. However, several characteristics of waves determine the quality of sound that is produced from those waves. These are *amplitude, frequency, spectrum* and *duration*, as listed e.g. by Gareth Loy in Musimathics [6] and by David Benson in [1].

*Amplitude* is the distance between the highest and lowest peaks of a wave, typically measured in millimeters (mm). *Frequency* is the rate of the periodic pressure change of a wave. This is derived from the number of times a certain point of interest on the wave is repeated per given unit of time. It is typically measured as the inverse of the number of seconds between the repetition, known as *Hertz*, denoted *Hz*. The *spectrum* of a wave is a visual representation of the various distinct frequency amplitudes within the sound. This can be thought of as the "shape" of the wave, so to speak. Lastly, the *duration* is the length of time for which the sound is sustained.

We can connect each of these characteristics to some distinct physical quality of sound [1]:

1. Amplitude — Varies directly with the loudness of the sound.

2. Frequency — Varies directly with the "highness" of the sound, also known as "pitch", which we will discuss soon.

3. Spectrum — Varies directly with the "timbre" of the sound, which we will also discuss shortly.

4. Duration — Varies directly with the length of the sound.

Imagine that you are listening to the radio on a long car-ride home, and a peculiar song comes on that seems to be a garbled mess of static and muddy noise. Obviously, this would not be a pleasant experience. Here it is evident that the beauty of music lies in its carefully structured nature. In order to accomplish this, composers and musicians have categorized various sounds based on a number of qualities, most notably, the pitch of the sound and the timbre of the sound.

*Pitch* can be thought of as the physical representation of the frequency of a sound wave[6]. *Timbre* is the semantic quality of a sound, such as bright, dull, heavy, etc. It depends heavily on spectral energy distribution and the evolution of said spectral energy distribution over time.

Pitch and timbre, along with the loudness of the sound, combine in western common musical practice, shortened as "CMN" for Common Musical Practice, to produce something known as a "tone". A *tone* is a unit of sound in CMN characterized by a certain pitch, musical loudness and timbre (see e.g. [6]).

However, ask any musician what kinds of sounds he or she produces on a regular basis, and the chances are that he or she will not reply with "tones", but with "notes" instead. In CMN, a *note* is a tone combined with a certain onset and duration [6].

The notes are, in essence, a representation in physical form of the exact type of sound-wave needed at a certain point in time. This point in time, the "onset" of the note, along with the duration of the note and pitch of the note, can be physically represented as something known as a *musical score*, which can then be read and played by a trained musician. In this score, notes played in succession, one right after the other, form what is called a *melody*, which often serves as the main point of focus for the song. Two or more notes played concurrently form what is called a *chord*, which form the musical soundscape of a piece of music. In order to fully appreciate melodies and chords, we first introduce and explore the concept of intervals.

In this section, an overview of the fundamentals of sound was presented. Then, some basic musical concepts were explored. Now, we shall transition into a discussion of more complicated musical topics pertaining to the organization of pitches.

## Intervals and Scales

An *interval* is the difference in pitch between two notes (see e.g. [6]). Recall that the frequency of a sound wave is measured in Hz. Suppose that you hear a sound wave of frequency f=440$Hz$. As it turns out, any sound wave with this frequency is denoted as *A440*, and is the pitch that most western orchestras use to tune together.

Consider the case where a second sound wave is then played, this time at:

$$f' = {}^{440Hz}/_2 = 220Hz = f/2$$

As it turns out, the sound wave $f'$ will have an extremely similar pitch to that of $f$. This phenomenon is designated as an "octave", and is one of the foundations of nearly all musical styles and traditions, as expressed by Fauvel, Flood, and Wilson in *Music and Mathematics: From Pythagoras to Fractals* [3]. Halving the frequency results in a sound that is an octave lower.

In order to generalize, let $f_x$ be some reference frequency, and let $f_x$ be a different frequency, where $x \in \mathbb{Z}$ represents the number of octaves above or below the reference frequency $f_0$ [6]. Then we have that:

$$f_x = 2^x f_x$$

Consider the case where $x = 0$. Then we state that $f_x$ and $f_0$ are in "unison", meaning that the two frequencies are the same.

As it so happens, "octave" and "unison" are only specific instances of an interval. In general, an interval can be represented by the equation:

$$f_x = x f_0$$

where $f_0$ is our reference frequency, $f_x$ is our interval frequency, and $x \in \mathbb{R}$ is a scaling factor [6].

Now consider the set $(\mathbb{R}^+)^2$, which consists of ordered pairs of the form $(f_x, f_y)$, with $x, y \in \mathbb{R}$. David Wright, in [7], presents an equivalence relationship on ordered pairs of frequences. We define a relation such that two ordered pairs:

$(f_x, f_y), (f_{x'}, f_{y'})$ are equal if and only if $f_x / f_y = f_{x'} / f_{y'}$

We designate the equivalence class of $(f_x, f_y) \in (\mathbb{R}^+)^2$ by $(f_x : f_y)$, notated as the ratio of $f_x$ and $f_y$. Notice that the function:

$$\phi: (\mathbb{R}^+ : \mathbb{R}^+)^2 \to \mathbb{R}^+$$

defined by:

$$\phi((f_x : f_y)) = f_x / f_y$$

is one-to-one, well defined, and onto [7].

This equivalence relation is used to connect a distinct ratio with each interval [7]. Let $f_1$ and $f_2$ be two frequencies. Let r=$f_2/f_1$. Then $r$ is the ratio of $f_2$ to $f_1$. We can then connect $r$ with $f_2:f_1$ through the function $\phi$.

The frequency ratios of the diatonic scale in CMN based on Pythagorean tuning [2], a tuning system which we will cover shortly, are listed in *Table 1*.

**Table 1.** Frequency Ratios of Diatonic Pythagorean Scale. Courtesy of Manuel O. Stichting de Coul [2].

| Interval | Frequency Ratio |
|---|---|
| Unison | 1:1 |
| Major Second | 16:15 |
| Major Third | 5:4 |
| Perfect Fourth | 4:3 |
| Perfect Fifth | 3:2 |
| Major Sixth | 5:3 |
| Major Seventh | 15:8 |
| Octave | 2:1 |

Using frequency ratios, musicians devise something called a *scale*, a discrete set of pitches used in making or describing music. Most commonly, a scale will consist of a discrete sequence of frequency ratios $r$ from some reference frequency $f_0$ to the nth frequency $f_n, n \in \mathbb{N}$, in the sequence, with the sequence repeating itself at the next octave of $f_0$ [7].

There are many different ways to divide up the octave into $n$ disparate ratios, with the interval between $f_{k-1}$ and $f_k$ called a semi-tone, where $k \leq n$. In this way, a scale is made up of $n$ semitones. For example, in CMN, the octave is divided up into 12 semitones [7]. Each note in a scale is then given a corresponding letter designation $\alpha$, where $\alpha \in \{A, B, C, D, E, F, G\}$.

The symbol $b$, which stands for "flat," lowers a given tone by one semitone. The symbol #, which stands for "sharp," raises a given tone by one semitone.

For a CMN chromatic scale beginning on A, we have the following intervals and notes (*Table 2*):

**Table 2.** CMN Chromatic Scale. Courtesy of David Wright, 2009 [7].

| Interval | Semitones | Pitch |
|----------|-----------|-------|
| Unison | 0 | C/B# |
| Minor Second | 1 | Db/C# |
| Major Second | 2 | D |
| Minor Third | 3 | Eb/D# |
| Major Third | 4 | E/Fb |
| Perfect Fourth | 5 | F/E# |
| Tritone | 6 | F#/Gb |
| Perfect Fifth | 7 | G |
| Minor Sixth | 8 | Ab/G# |
| Major Sixth | 9 | A |
| Minor Seventh | 10 | Bb/A# |
| Major Seventh | 11 | B/Cb |
| Octave | 12 | C |

Different scales such as the major, minor, Hungarian minor, etc., can all be formed from the intervals shown above. In fact, we can categorize different scales based on their interval order [6]. That is, beginning from the first pitch, called the first scale degree, we list the number of semitones between the $n$ pitch and the $n-1$ pitch, where $n \in N$, in a sequence.

We continue this process until we reach the first scale degree of the next octave. For example, the pitch sequence of a diatonic (major) scale in CMN would be {2,2,1,2,2,2,1}. Notice that abstracting the scale in this manner removes the need to know the exact starting pitch in order to analyze the scale [6]. Now, any arbitrary starting pitch may be utilized.

Recall that $f = 440\ Hz$ is the pitch A. As was previously discussed, we can scale the frequency of this note by 1/2 and obtain the pitch $f' = 1/2\ f = 220\ Hz$. However, this note will have the same "pitch" and simply be an octave lower than our original pitch. Hence, it is also given the designation A. The same holds for $f'' = 2f = 880\ Hz$, which, since it is simply our original pitch an octave higher, is also given the designation A. Then, the two notes are both given the same *pitch class*, [A]. Two notes are in the same pitch class if and only if the two notes are an octave apart [7].

Now, let f=$x$ Hz be an arbitrary pitch with designation:

$$\alpha \in \{A,B,C,D,E,F,G\},$$

where $x \in \mathbb{R}$.

Define a pitch designation $\beta_m$ as the pitch with frequency:

$$f_m = 2^m f = 2^m x\ Hz,$$

where $m \in \mathbb{Z}$

Then we have that the pitch equivalence class of $\alpha$ is the set:

$$[\alpha] = \{\beta_m : m \in \mathbb{Z}\}$$

So, in our previous example, $f, f', f'' \in [A]$. By convention, $f$ is designated as $A_4$, while $f' = 2^1 f$ is designated as $A_{4-1} = A_3$, and $f'' = 2^1 f$ is designated as $A_{4+1} = A_5$. Thus, $f, f', f''$ are all equivalent modulo pitch class.

In CMN, it is common practice to have a given scale begin on C. However, by using the interval order associated with a given scale, we may begin a given scale on any arbitrary pitch. If we begin the scale on C, then the scale is said to be untransposed and is in the key of C.

In the case where the scale begins on a different pitch, say, G, then the scale is said to be transposed, and is in the key of G. In this case, the scale has been transposed up 7 semitones, or equivalently, the scale has been transposed down 5 semitones. For another example, if the scale were to be transposed down an octave, it would still be the same scale, untransposed [6].

To understand this, consider that in transposing a scale up or down $n$ semitones, $n \in \mathbb{N}$, each scale degree is transposed $n$ semitones up or down as well, with the direction of transposition of the scale degree coinciding with the direction of transposition for the entire scale. Hence, if a scale were to be transposed down an octave, each individual scale degree would also be transposed down an octave. Then each transposed scale degree remains equivalent modulo pitch class to its respective untransposed scale degree, and thus each pitch remains the same. Consequently, the scale remains untransposed.

One can think of it as being similar to the situation of replacing the graph of $y = f(x)$ by the graph $y = f(x) + c$, performed under some modulo $c$ addition, where $c \in \mathbb{N}$ [7].

Recall the pitch sequence of the major scale in CMN: {2,2,1,2,2,2,1}. Now, consider the first cyclic permutation of this sequence: {2,1,2,2,2,1,2}. As the intervals between the scale degrees have been altered, the scale with this degree sequence is not a transposition of the major scale. In fact, observe that the second and sixth scale degrees have been transposed down a semitone, while the third and seventh scale degrees have been transposed up a semitone. Hence, it is impossible for this to be a transposition, since it would require some scale degrees to transpose up and others to transpose down, which contradicts the definition of transposition [7].

Instead, this degree sequence is known as a *mode* of the original degree sequence, in this case being the second mode [6]. The major scale has seven different modes, one for each possible cyclic permutation of its degree sequence, which can be observed in *Table 3*.

**Table 3.** The Modes of the Diatonic Scale. Courtesy of Gareth Loy, 2006 [6]..

| Mode | Name | Degree Sequence |
|------|------|-----------------|
| 1 | Ionian (Major) | {2,2,1,2,2,2,1} |
| 2 | Dorian | {2,1,2,2,2,1,2} |
| 3 | Phrygian | {1,2,2,2,1,2,2} |
| 4 | Lydian | {2,2,2,1,2,2,1} |
| 5 | Mixolydian | {2,2,1,2,2,1,2} |
| 6 | Aeolian (Minor) | {2,1,2,2,1,2,2} |
| 7 | Lochrian | {1,2,2,1,2,2,2} |

However, the concepts of modes is not limited only to the major scale. In fact, for each distinct degree sequence of $n$ entries, where $n \in N$, there exists anywhere between 1 to n different modalities, depending on the order of the degree sequence; that is, depending on the minimum number $k$ of cyclic permutations before the original degree sequence resurfaces, where $1 \leq k \leq n$. For example, if a sequence of numbers has a cyclic order of 3, then that sequence has 3 different modes. In fact, the concept of modality is practically equivalent to the mathematical concept of a cyclic group and its distinct elements.

Consider a note in the pitch class [C]. Transpose this note up a fifth, and the note is now in the pitch class of [G]. Doing this again, we arrive at [D]. We continue this pattern for a total of 12 repetitions, at which point we arrive once again at the pitch class [C], only this time our pitch has been

transposed up the equivalent of 7 octaves. These 12 transpositions form what is called the *circle of fifths*, and is extremely useful for reasons of compositional ease and utility [6].

In a perfect world, we could create this circle of fifths using only the rational frequency ratios discussed beforehand. Unfortunately, doing this results in a Pythagorean comma, which is a ratio of 531441 / 524288 between where we would end up and where we want to end up, i.e., between where we start and where we end up after transposing up 12 fifths, then down 7 octaves [1].

This comes from the difference between going up 12 fifths:

$$(3/2)^{12} = 3^{12} / 2^{12}$$

and going down 7 octaves:

$$(1/2)^7$$

Doing so results in the ratio:

$$3^{12} / 2^{12} \cdot 1 / 2^7 = 3^{12} / 2^{19} = 531441 / 524288 \approx 1.014 \neq 1$$

This peculiarity leads us into a discussion of different types of tuning systems, and the reasons behind why different tuning systems would be needed in the first place.

With the fundamentals of intervals now detailed, we may move on to an exploration of musical tuning systems.

## Tuning Systems

As a consequence of the physics of fundamentals and overtones, intervals corresponding to small-integer frequency ratios usually sound cleaner and more consonant or in-tune. As a result of this fact, many different types of tuning systems have emerged over the centuries [3]. For those that are built upon scales whose sequence repeats with the octave, they can be classified as one of the following five: Pythagorean, just, meantone, equal and irregular. However, nearly all tuning systems are based around the octave.

The octave is considered to be the most consonant non-unison interval, so nearly all music traditions base their scales and tuning systems around the 2:1 ratio of the octave [3]. For CMN in particular, the octave is usually divided up into a 12-tone chromatic scale. However, in order to ascertain the tuning properties of different scales and tuning systems, the cents system was created.

Take an octave and divide it into 1200 equal units called cents. That way, each semitone in the CMN 12-tone chromatic scale will have a range of 100 cents, simplifying many calculations. Because octaves deal with powers of 2, this is a logarithmic scale of measurement . In order to convert from a frequency ratio, r:1, to cents, use the following conversion [1]:

$$1200\log_2(r) = 1200\ln(r)) / (\ln(2)$$

To convert from an interval of $n$ cents to a frequency ratio:

$$2^{n/1200} : 1$$

Utilizing this system, a precise measurement of intervals can be made. For reference, for an untrained ear, a difference of up to 30 cents is imperceptible, while for a trained ear, a difference of up to 5 cents is imperceptible [3].

We should also discuss the concept of harmonics. As anyone familiar with Fourier analysis can tell you, any sound-wave with some frequency $f$ can be decomposed as a sum of sine waves with various phases at integer multiples of the frequency $f$. The sine wave with frequency $f$ of the sound-wave is known as the fundamental. Let $m \in \mathbb{N}$. Then the component sine wave with frequency $mf$ is known as the $m$th harmonic, or, equivalently, the $(m-1)$st overtone. This is designated as *harmonic partial*. In contrast, an inharmonic partial is a component sine wave with a frequency that is not a positive integer multiple of the fundamental [1].

This feature of sound waves is the reason behind the consonance of the octave and perfect fifth intervals. If two notes, say $A_3$ and $A_4$, an octave apart, hence with a ratio of 2:1, are played concurrently, then their partials will coincide, in that the second partial of $A_3$ will be the first partial of $A_4$, and the $(k+1)$st partial of $A_3$ will be the $k$th partial of $A_4$, where $k \in \mathbb{N}$ [1]. So, no partials conflict with each other, and hence no roughness occurs to the ear. In fact, this is why our ears perceive the two notes as having the "same" pitch.

Similarly, when two notes, say, $A_4$ and $E_5$, a perfect fifth apart, so with a ratio of 3:2, are played concurrently, then the third partial of $A_4$ will coincide with the second partial of $E_5$ [1]. Additionally, other partials higher up will coincide as well. So, although not every partial perfectly coincides, enough coincide so as to produce a very consonant-sounding interval between the two notes.

Pythagoras was the first to discover the consonant properties of the 3:2 perfect fifth interval ratio [3]. He also made great use of the 2:1 octave ratio. Due to his personal beliefs, Pythagoras believed that a good scale could be created using only these two interval ratios.

To create the second, third, sixth and seventh scale degrees of the diatonic Pythagorean scale, we follow a specific construction [1].

1. Begin with some reference frequency, say, $f_0 = 1$.

2. Utilize the ratio 3:2 twice to obtain a ratio of 9:4 which is slightly larger than 2:1.

3. Transpose down an octave by utilizing 1:2, resulting in a ratio of 9:8. This is the Pythagorean major second.

4. Utilize the ratio 3:2 to obtain a ratio of 27:16. This is the Pythagorean major sixth.

5. Utilize the ratio 3:2 again to obtain a ratio of 81:32 which is slightly larger than 2:1.

6. Transpose down an octave by utilizing 1:2, resulting in a ratio of 81:64. This is the Pythagorean major third.

7. Utilize the ratio 3:2 once more to obtain the ratio 243:128. This is the Pythagorean major seventh.

Obtaining a Pythagorean fourth, fifth and octave is then obtained through similar multiplications using the same ratios. The scale degrees and ratios of the Pythagorean major scale are displayed in *Table 4* [2].

**Table 4.** The Pythagorean Major Scale. Courtesy of Manuel O. Stichting de Coul [2].

| Scale Degree | Ratio | Cents |
|---|---|---|
| 1 | 1:1 | 0.000 |
| 2 | 9:8 | 203.910 |
| 3 | 81:64 | 407.820 |
| 4 | 4:3 | 498.045 |
| 5 | 3:2 | 701.955 |
| 6 | 27:16 | 905.865 |
| 7 | 243:128 | 1109.775 |
| 8 | 2:1 | 1200.000 |

Notice that between two notes in this system, we have the interval ratios of 9:8 for a whole step and $2^8:3^5$ for a half step. However, the half step, or semitone, is not quite equal to half of a whole step [1]. Indeed, we have that two semitones

give a ratio of $2^{16}:3^8$, which is not equal to 9:8, but rather is off by:

$$3^{12}:2^{19} = 1.0136... \approx 1$$

So, going up by 12 fifths and then back down by 7 octaves, i.e.,

$$(3^{12} / 2) \cdot (1/2)^7 = 3^{12} / 2^{19}$$

results in nearly the same starting pitch, but not quite [1]. This difference of a ratio of $3^{12}:2^{19}$ is known as the *Pythagorean comma*, which frustrated composers for centuries [3].

The Pythagorean scale was the first true musical scale and was firmly entrenched for many centuries as the most commonly used scale [3]. However, a periodic circle of fifths cannot be created using this tuning system, and thus transposition and modulation within the tuning system is limited. As composers grew bolder and bolder with their compositional styles and use of transposition and modes, the scale gradually fell out of favor.

*Just intonation* refers to any tuning system that uses small, whole numbered ratios between the frequencies in a scale. In order to obtain these small, whole numbered ratios, we turn to the harmonics of a note, in a process described by Leon Harkleroad in *The Math Behind the Music* [5]. Given a starting note, we can look at the harmonics of that note and find small, whole numbered ratios that line up with useful interval ratios such as perfect fifths, fourths, octaves, etc. The only caveat is that these ratios occur at higher partials, so we must bring each down some number of octaves, and that the same interval may produce different ratios for different note combinations.

The intervals for the just intonation major scale are listed in *Table 5* [1].

**Table 5.** Just Major Scale. Courtesy of David J. Benson, 2013 [1].

| Scale Degree | Ratio | Cents |
|---|---|---|
| 1 | 1:1 | 0.000 |
| 2 | 9:8 | 203.910 |
| 3 | 5:4 | 386.314 |
| 4 | 4:3 | 498.045 |
| 5 | 3:2 | 701.955 |
| 6 | 5:3 | 884.359 |
| 7 | 15:8 | 1088.269 |
| 8 | 2:1 | 1200.000 |

Notice that the three major triads, being, with scale degrees listed, the I - 1,3,5, the IV - 4, 6, 8, and the V - 5, 7, 2, all have frequency ratios of 4:5:6. This is what defines just intonation.

In essence, just intonation refers to a tuning system in which each of the three major triads have a frequency ratio of 4:5:6 [1]. The differences between different types of just intonation tuning systems arises when the remaining notes of the 12-tone scale are filled in, resulting in various commas that may even alter the tuning of the notes listed in Table 5.

Beginning with either a Pythagorean or just scale, at some point after a sufficient number of intervals, one will reach a note that is very nearly the same as a previously encountered note, but not quite the same note. This results in the formation of some type of comma.

In order to eliminate this comma, one may be tempted to spread out the comma across some of the notes of the scale, so as to lessen the impact of the comma on an individual pitch and instead have its effects become smaller and smaller until they are negligible. Performing this action results in the formation of a *tempered scale* [3]. Although there are many different ways to accomplish this goal, one in particular stands out at the moment.

A *Meantone Scale* is a tempered scale constructed by adjusting the fifths of a Pythagorean or just scale by some fraction of a syntonic comma [1].

The most common meantone scale is the *quarter-comma meantone scale*. To form this scale, a reference frequency is chosen as scale degree one, and then the ratio 5:4, a major third, is used to create more scale degrees within the cycle of major thirds [1].

The remaining notes are inserted between the major third intervals in such a way that they are as spread out as possible. Due to the logarithmic nature of scales, exponents are required to accomplish this goal. As the scale is constructed using the ratio 5:4, the square root of said ratio, $\sqrt{5}/2$, is used to insert notes in between the intervals constructed by the major third [1].

The general interval ratios for a quarter-comma meantone major scale are listed in Table 6 [1].

**Table 6.** Quarter-Comma Meantone Major Scale. Courtesy of David J. Benson, 2013 [1].

| Scale Degree | Ratio | Cents |
|---|---|---|
| 1 | 1:1 | 0.000 |
| 2 | $\sqrt{5}$:2 | 193.157 |
| 3 | 5:4 | 386.314 |
| 4 | $2:5^{1/4}$ | 503.422 |
| 5 | $5^{1/4}$:1 | 696.579 |
| 6 | $5^{3/4}$:2 | 898.735 |
| 7 | $5^{5/4}$:4 | 1082.892 |
| 8 | 2:1 | 1200.000 |

Using *Table 6*, observe that starting on the note C, we have that C-D-E is in the ratio $1:\sqrt{5}/2:5/4$. This would then also hold for F-G-A and G-A-B. Equivalently, one could say that each fifth interval is decreased by exactly one quarter of a comma from its Pythagorean value.

Interestingly enough, one can use a visual known as *Eitz's notation* to describe not only the meantone scale, but any arbitrary scale. In Eitz's notation, the scale begins with C, and each scale degree's pitch class is listed, ending at the C an octave up [1] . Then, the number of commas that each individual scale degree differs from its respective Pythagorean counterpart is listed in superscript next to each respective scale degree, where +*n* denotes "up" *n* commas, and -*n* denotes "down" *n* commas, where $n \in \mathbb{Z}$.

So, the meantone scale in Eitz's notation is as follows:

$$C^0 - D^{-1}/_2 - E^{-1} - F^{+1}/_4 - G^{-1}/_4 - A^{-3}/_4 - B^{-5}/_4 - C^0$$

Additionally, the Pythagorean and just intonation scales can be listed as well. The Pythagorean scale is as follows:

$$C^0 - D^0 - E^0 - F^0 - G^0 - A^0 - B^0 - C^0$$

Next, the just intonation scale is listed out as such:

$$C^0 - D^0 - E^{-1} - F^0 - G^0 - A^{-1} - B^{-1} - C^0$$

A variation of Eitz's notation exists in which the notes are listed out in an array format, depending on the pattern of commas [1]. We will use this form to layout the general form of the α-comma meantone temperament, of which we have been previously looking only at the case where α = $^1/_4$, as presented by Benson in *Music a Mathematical Offering* [1].

$$E^{-4\alpha} \quad B^{-5\alpha} \quad F\#^{-6\alpha} \quad C\#^{-7\alpha} \quad G\#^{-8\alpha}$$
$$C^0 \quad G^{-\alpha} \quad D^{-2\alpha} \quad A^{-3\alpha} \quad E^{-4\alpha}$$
$$Eb^{+3\alpha} \quad Bb^{+2\alpha} \quad F^{+\alpha} \quad C^0$$

Note how the top, middle and bottom row all proceed by fifth intervals. Also, notice that taking two adjacent notes in the middle row and the note between them in the top row forms a major triad, while taking two adjacent notes in the middle row and the note between them in the bottom row forms a minor triad.

Here, it should be noted that the meantone scale still has a few shortcomings. Namely, the fact that it is still difficult, if not impossible, to freely transpose the scale around the circle of fifths. This is because the pitches of the meantone scale do not fully meet up, and rather connect via a *wolf* fifth, i.e., a noticeably out of tune fifth to match up the lowest tempered and highest tempered pitches [3].

In visual terms, as the meantone scale is constructed, creating a circle of fifths is impossible for similar reasons as the Pythagorean scale. So, if one were to attempt to make a two-dimensional circle, they would instead create a three-dimensional spiral whose ends do not meet up.

To get around this, an imperfect circle of fifths is created by joining together two points of the spiral that are relatively close in terms of pitch [1]. This just so happens to be the lowest and highest pitches resulting from the construction of the meantone scale, and these pitches are close, but not quite, to being a fifth away from each other, after transposing octaves as needed.

*Irregular temperament* refers to a temperament in which a meantone scale has been altered in such a way that the notes at the very ends of the circle of fifths have been warped to meet so as to remove the issue of the wolf fifth [1]. In other words, rather than having the wolf fifth occur between only two notes, the comma of the wolf fifth has been spread out over several fifths, so as to mitigate its impact.

So, referring back to Eitz's notation array, rather than simply having the α term change in such a consistent pattern, the comma is altered to be more evenly spread out [1]. However, this results in each key having its own unique style and flavour, due to the placement and alterations of different fifths around the circle of fifths.

Regardless, a wide variety of irregular temperaments have been utilized throughout musical history, and the irregular temperament is celebrated as the first widely-utilized key which is able to be transposed around the circle of fifths, albeit in a very round-about and convoluted manner [3].

The one shortcoming of each of the previously explored tuning systems has been lack of easy transposition from one key to the next. At best, a few adjacent key signatures are made to sound good while the rest are better-left unsaid. In return, pure, in-tune intervals can be found and utilized frequently within the tuning systems, allowing for unblemished, or nearly-so, music to occur. It would seem that, in order for fluid transposition between keys to take place, something must give.

For all the previously discussed tuning systems, two or more interval-sizes exist between adjacent chromatic notes. In contrast, an *equal-tempered tuning system* is one in which each interval between adjacent chromatic notes is the same size [7]. For a twelve-tone equal-tempered tuning system, the octave is split up into 12 equally-sized intervals.

Recall that an octave has a ratio of 2:1. So, to create 12 equally-sized intervals, we want an interval such that multiplying the interval by itself 12 times produces an octave [5]. Hence, the semitone of a twelve-tone equal-tempered tuning system is given the ratio:

$$2^{1/12}:1$$

Meanwhile, the whole tone is given the ratio:

$$2^{1/6}:1$$

The ratios for the diatonic scale in twelve-tone equal-temperament are listed in Table 7 [1].

**Table 7.** The Equal-Tempered Major Scale. Courtesy of David J. Benson, 2013 [1].

| Interval | Ratio | Cents |
|---|---|---|
| Unison | 1:1 | 0.000 |
| Major Second | $2^{2/12}:1$ | 200.000 |
| Major Third | $2^{4/12}:1$ | 400.000 |
| Perfect Fourth | $2^{5/12}:1$ | 500.000 |
| Perfect Fifth | $2^{7/12}:1$ | 700.000 |
| Major Sixth | $2^{9/12}:1$ | 900.000 |
| Major Seventh | $2^{11/12}:1$ | 1100.000 |
| Octave | 2:1 | 1200.000 |

Using equal-temperament, every key is immediately available for use. However, in return, no perfectly-tuned intervals remain, with the major third interval being particularly out of tune with its Pythagorean counterpart, sharp by approximately 14 cents [1].

It should be noted that although the use of 12 notes in a chromatic scale in CMN is not arbitrary, n-note scales and temperaments do exist as well, where $n \in N$. For example, Harry Partch devised a 43-tone scale in which he uses the primes 2,3,5,7 and 11, known as 11-limit, rather than just the 3-limit of the Pythagorean scale, or the 5-limit of the just-intonation scales [1].

Furthermore, 53-tone and 19-tone equal temperaments exist and are somewhat widely-used. They both offer purer tuning than the 12-tone equal temperament; however, this comes at the cost of feasibility of score-writing [3]. It is quite difficult to fit 53 possible notes onto a five-bar staff.

We have now introduced various concepts in regards to the quality, pitch and characteristics of sound waves, the categorization and sequencing of musical pitches and tuning system. However, we must now investigate methods in which to describe the duration of a pocket of sound waves in a way that is feasible transcribe to paper.

## Horizontal Structure

On a musical score, the *x*-axis represents the change in time, from left to right, while the *y*-axis represents the pitch, from the bottom on up. To draw a parallel to mathematics, just as we often measure the change in time on the *x*-axis of a graph, so too do music theorists and musicians measure the change in time on the *x*-axis of a graph, in this case being the musical score. [7]. However, rather than having the change in time be measured by a continuous spectrum of infinitely tiny units as in analysis, musicians use discontinuous, finite units known as beats to measure the change in time for a piece of music.

The speed at which a piece is played, i.e., how many seconds each beat is given before moving onto the next beat, is measured in BPM, which stands for beats per minute. This measurement is referred to as the *tempo* of a piece. In order to know how many beats a certain pitch should be played for, a note is placed in a certain location,

with the *x*-coordinate determining the onset beat on which to play the pitch, the y-axis determining the actual pitch to play.

The characteristics of the note head determine the duration for which to play the pitch. These characteristics involve visual cues such as stem flags, dots, ties, the color of the note head and more, with each cue informing the musician of just how long to hold the note. In CMN, the duration of a note is based on the whole note, which has a duration in beats determined by a *time signature* [7].

In CMN, a piece of music is divided up into pockets of n beats, where $n \in \mathbb{N}$, known as *measures* [7]. Each measure has a certain time signature which dictates the number of beats within that measure, as well as declaring exactly which durational note is assigned the value of one beat for its duration.

To be specific, the time signature is composed of two values, *n* and *r*, where $n \in \mathbb{N}$ and $r \in \{2^\alpha : \alpha \in \mathbb{Z}\}$ [7]. These two values are stacked on top of each other, as such:

$$\frac{n}{r}$$

The top value, n, specifies the number of beats within the measure, while the bottom value, $r = 2^\alpha$, specifies that the $2^{-\alpha}$th note is assigned a value of one beat [7].

For example, the time signature:

$$\frac{2}{4}$$

indicates that the measure consists of 2 beats, with the quarter note being assigned a value of one beat.

However, there is a special class of time signatures, known as compound time signatures, for which the rules differ just slightly [7]. Any time signature for which:

$$3 \text{ divides } n \quad and \quad n > 3$$

is classified as a compound time signature.

In this case, the number of beats to a measure is designated as $n/3$, as opposed to simply *n*. This implies that three notes with a value of $2^{-\alpha}$ give one beat [7]. Hence, one beat is given by a dotted $2^{-(\alpha-1)}$th note, where a dot multiplies the durational value of a note by $3/2$.

So, for example, consider the case where a measure has a time signature of:

$$\frac{6}{8}$$

In this instance, there are $6/3$ = 2 beats per measure, and one beat is given by three $2^{-3} = 1/8$th notes, which is equivalent to a dotted $1/4$ note.

Hopefully, you have noticed a pattern by now. That is, given a note of some value β, where $\beta \in \mathbb{Q}$, that note can be divided in half into two notes of durational value $1/2\,\beta$. This is no coincidence. In fact, given any note β, you are permitted in CMN to break it up into $2^m$ notes each with a durational value of $1/2^m\beta$, where $m \in \mathbb{N}$ [6].

Beginning with the whole note, , and dividing by 2 with each successive listing, we arrive at the half note, , the quarter note, , the eighth note, , the sixteenth note, , the thirty-second note, , the sixty-fourth note, , and so on [7]. Notice that the whole note and the half note do not have flags.

Beginning with $n \geq 2$ , the $2^{-n}$th note is written with a filled note head [7]. For $n \geq 1$, every $2^{-n}$th note has a note stem. Additionally, for n ≥ 3, the note stem is given n − 2 flags.

Sometimes, adjacent notes may be connected by beams, which replace the flags on each note [7]. In between the onset of notes, when no music is meant to be played, a rest is placed instead, which follows the same rules as those for a note.

As was previously mentioned, a dot next to a note head extends the duration of that note by a factor of $3/2$ [6]. So, for example, a dotted quarter note, , has the same duration as three eighth notes. There is no limit on the number of dots that may be added to an individual note.

Suppose that there exists a note of duration d. Next, suppose that this note is followed by *m* dots, giving it a new duration designated $d_m$, where $d \in \mathbb{Q}^+$ and $m \in \mathbb{N}$. So, the duration of the note is now:

$$d_m = d(1 + 1/2 + 1/2^2 + \ldots + 1/2^m)$$

$$= d\sum_{i=0}^{m} (1/2)^i$$

$$= d[(1 - (1/2)^{(m+1)}/1 - 1/2]$$

$$= d[2(1 - (1/2)^{m+1})]$$

$$= d[2 - (1/2)^m]$$

Thus, a note of duration d followed by m dots has duration:

$$d_m = d[2 - (1/2)^m]$$

Consequently, as m becomes larger and larger, we have the following result [7]:

$$\lim_{m\to\infty} d_m = \lim_{m\to\infty} d[2 - (1/2)^m] = 2d$$

Hence, in essence, adding an infinite number of dots to a single note would be the same as scaling the durational value of that note by a factor of 2. Of course, it is highly doubtful that any composer would ever attempt to use even more than 3 or 4 dots on a single note. At that point, it would be more efficient and much more beneficial, both for the composer and the musician, to change the note itself to a different durational value, rather than simply adding more and more dots.

As a rule, musicians and composers prefer to utilize notes with durations that are $2^{-n}$ times some beat unit. However, sometimes the situation may arise where $k$ notes of equal duration are required such that the duration of each is not a power of 2. So, in order to divide a $2^{-n}$th note into $k$ equal notes, where $n \in \mathbb{N}$ and $k \neq 2$, we form a $k$-tuplet by finding the unique positive integer $r$ such that

$$2^r < k < 2^{r+1}$$

and designating the tuplet as a group of $k2^{n+r}$th notes overset or underset by the integer $k$ [7]. That is, we write the integer $k$ over or under the bars connecting the notes, as necessary. This is actually one of the simplest versions of *polyrhythms* that exists, where polyrhythm designates the concept of two rhythms being played simultaneously, and a rhythm is defined as being a certain pattern of beat onsets that may or may not repeat throughout the piece of music.

To be more precise, *rhythm* is a musical construction through which time is organized in measures through the careful patterning of beat onsets and durations [7]. There are many types of rhythms that exist within music, all based around certain types of pattern structures and mathematical combinatorial designs.

An example is the polyrhythms that were previously mentioned, as well as something known as a *Euclidean rhythm*, detailed by Gómez-Martin, Taslakian, and Toussaint in *Interlocking and Euclidean Rhythms* [4]. A Euclidean rhythm

occurs whenever a certain number of beat onsets are spaced out as evenly as possible among a certain number of total beats. Oftentimes, rhythms are periodic and repeating in nature, while in other instances a rhythm can be instantaneous and unique within the piece.

As previously discussed, *melody* is the succession of notes that features most prominently in a piece of music. Many times, the melody may be on its own, without any sort of background accompaniment or texture. At other times, a melody may be joined by several other patterns of successions of notes, known as counter melodies. A melody is defined not only by the sequence of pitches within the melody, but also by the duration and onset of the pitches as well, i.e., the rhythm. A melody will often introduce and even reinforce the key of a piece as well.

It should also be noted that a melody may involve repetition and can be characterized by the pattern of its repetition, known as its *form* [7]. For example, a melody may start off with a two-measure sequence of notes, also known as a two-measure *phrase*. We denote this as the A section. Next, a slightly modified version of the original two measure phrase may be played, denoted as $A'$. Then, a melody may introduce a different kind of phrase separate from either $A$ or $A'$, denoted as $B$. Lastly, perhaps the melody reintroduces $A$. In this case, the form of the melody would be $AA'BA$.

Now that we have a solid grasp of the transcription of music and its visual representation, we can move on to an exploration of the various transformations that can be performed within music.

## Musical Transformations

Consider the manner in which a function $y = f(x)$, where $y, x \in \mathbb{R}$, can be translated along the $x$ axis left or right by some amount $c$, where $c \in \mathbb{R}$, on the two-dimensional Cartesian coordinate system. This is done by utilizing:

$$y = f(x + c)$$

Additionally, letting a melody be $x$, $x$ can be translated left or right by a certain number of beats, $c$, to create a new melody $y$ that is equivalent to the melody $x$ shifted over by some number of beats, $c$ [7]. This is often used to vary the style or substance of a melody without having to alter its pitches at all.

Just as a scale can be transposed some number of semitones, so too can a melody be transposed to a different key. For example, suppose that we have a melody in the key of $C$, and we would like to transpose it to the key of $E$, which is a major third, or four semitones, up from the key of $C$. To transpose the melody to the key of $E$, we simply raise up each individual pitch within the sequence of pitches of the melody by a major third, or four semitones. Consequently, the melody is now in the key of $E$.

Let $x_y$ be some melody in the key of $y$, where $y$ is an element of the set of all keys, and denote $T_n$ as an automorphism function within the set of all possible melodies, where $n \in \mathbb{Z}^+$. We denote $T_n$ as a transposition by n semitones and $T_n(x_y) = x_{y+n}$, where $x_{y+n}$ is a melody isomorphic to $x$ in the key of $y + n$ [5].

Note that in CMN, in which 12-tone equal temperament is standard, we have that $n,y \in \mathbb{Z}_{12}$. Hence, a translation up by one semitone is pitch equivalent to a translation up by 13 semitones [5]. In other words:

$$T_m(x_y) = T_k(x_y) \text{ if and only if } m \equiv k \pmod{12},$$

$$\text{where } m,k \in \mathbb{Z}$$

It should also be noted that multiple transpositions can be performed in successive fashion. In general:

$$T_m\, T_k = T_{m+k} = T_{k+m} = T_k\, T_m$$

In other words, performing a transposition up $m$ semitones followed by a transposition up $k$ semitones is the same as performing a transposition up $m + k$ semitones. By the commutative property of addition modulo 12, we have that $m + k = k + m$. Thus, performing a transposition up m+k semitones is the same as performing a transposition up $k + m$ semitones, and this is equivalent to performing a transposition up $k$ semitones followed by a transposition up $m$ semitones [5].

Transposition forms a group with the composition operation that is isomorphic to $(\mathbb{Z}_{12},+)$ [5]. The functional composition table of all possible combinations of two of the 12 possible transpositions in CMN is presented in *Table 8*:

**Table 8.** Transposition Table. Courtesy of Leon Harkleroad, 2006 [5].

|  | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_0$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ |
| $T_1$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ |
| $T_2$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ |
| $T_3$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ |
| $T_4$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ |
| $T_5$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
| $T_6$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
| $T_7$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ |
| $T_8$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ |
| $T_9$ | $T_9$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ |
| $T_{10}$ | $T_{10}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ |
| $T_{11}$ | $T_{11}$ | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ |

Let a be some pitch in a scale with n scale degrees, where $n \in \mathbb{N}$. Denote $n_0$ as the 1st scale degree of the scale, also known as the *tonic*. We define the inverse pitch, $a^{-1}$, of $a$, as the pitch such that $a + (a^{-1}) = n_0 = (a^{-1}) + a$, where + denotes addition modulo $n$. It should be noted that as a rule, $a^{-1} = -a$.

We now turn to the concept of inverting a melody. Let $x$ be an element of the set of all pitch sequences, i.e., the set of all melodies. Let $I$ be an automorphism function within the set of all pitch sequences. Define an inversion, denoted $I(x)$, as the function that replaces each pitch within the sequence $x$ with its inverse pitch [1].

So, if $x$ is the pitch sequence:

$$4 - 6 - 5 - 1 - 0,$$

Then:

$$I(x) = 8 - 6 - 7 - 11 - 0$$

Note that an inversion can be functionally composed with a transposition, and vice-versa. For example, let $x$ be the pitch sequence:

$$1 - 2 - 3 - 5 - 0$$

Then:

$$T_6\, I(x) = T_6\, I(1 - 2 - 3 - 5 - 0)$$
$$= T_6(11 - 10 - 9 - 7 - 0) = 5 - 4 - 3 - 1 - 6$$

Once more, let $x$ be some sequence of pitches. Let $R$ be an automorphism function from the set of all pitch sequences onto the set of all pitch sequences. Define retrograde, denoted $R(x)$, as the function that reverses the order of succession of the pitches that make up $x$ [1].

In other words, R(x) takes the 0th pitch in x and switches it with the kth pitch in x, where k∈N. Then, $R(x)$ takes the nth pitch in x and switches it with the $(k − n)$th pitch, where $0 ≤ n ≤ {}^k/_2$. In essence, playing $R(x)$ is equivalently to playing x backwards.

Once again, it should be noted that $R(x)$ can be functionally composed with both itself and both $I(x)$ and $T(x)$ [1].

For example, let x be the pitch sequence:

$$5 − 8 − 10 − 11 − 7 − 0$$

Then:

$$R(I(T_5(x))) = R(I(T_5(5 − 8 − 10 − 11 − 7 − 0)))$$

$$= R(I(10 − 1 − 3 − 4 − 0 − 5))$$

$$= R(2 − 11 − 9 − 8 − 0 − 7) = 7 − 0 − 8 − 9 − 11 − 2$$

A *pitch class set* is defined as a subset of the set of 12 pitch classes in CMN [1]. In CMN the set of all pitch classes is the set:

$$\{0,1,2,3,4,5,6,7,8,9,10,11\}$$

Two pitch class sets are said to be equivalent if and only if one can be obtained from the other by using the operations $T_n$ or $I$ [1]. This means that the equivalence classes are the orbits of the dihedral group $D_{24}$ generated by $T_n$ and $I$ on the power set of $\{0,1,2,3,4,5,6,7,8,9,10,11\}$.

So, the total number of orbits of $D_{24}$ on each possible size of pitch class set is presented in *Table 9* [1].

Table 9: Orbits of Pitch Classes. Courtesy of David J. Benson, 2013 [1].

| Order of Subset | Number of Orbits |
|---|---|
| 0 | 1 |
| 1 | 1 |
| 2 | 6 |
| 3 | 12 |
| 4 | 29 |
| 5 | 38 |
| 6 | 50 |
| 7 | 38 |
| 8 | 29 |
| 9 | 12 |
| 10 | 6 |
| 11 | 1 |
| 12 | 1 |

Using these orbits, we are able to attach an invariant to each subset of $\{0,1,2,3,4,5,6,7,8,9,10,11\}$ [1]. First, suppose we have an unordered pair of distinct pitch classes. We can then assign a difference between the value of the two pitch classes, obtained by counting the shortest number of steps around the circle of pitch classes needed in order to arrive at one pitch class from the other pitch class. As a result, this difference will be between 1 and 6, with 0 being omitted due to the uniqueness of pitches within a pitch class set. Given a pitch class set of a certain size, we compute the difference between all unordered pitch class pairs that can be formed from the elements of the pitch class set.

Next, we record in a row vector how many times each unique difference value occurs for the pitch class set [1]. For example, consider the pitch class set {1,5,7}. The differences are 4,2,6, so the values will be recorded in a row vector, known as the *interval vector*, (0,1,0,1,0,1), where the nth entry in the interval vector represents the number of difference intervals of n semitones for the pitch class set in question, where $1 ≤ n ≤ 6$.

It should be noted that equivalent pitch class sets produce equivalent interval vectors, but the converse is not always true [1]. To see this, note that the pitch class set {3,7,9} produces the interval vector (0,1,0,1,0,1), and can be obtained from the pitch class set {1,5,7} by the operation $T_2$, and hence are equivalent.

However, the sets {0,1,4,6} and {0,1,3,7} both produce the interval vector (1,1,1,1,1,1) but are not equivalent, as no operation $T_n$ or $I$ can change one into the other, or vice-versa.

Now, a pitch class set is in *prime* form if and only if the pitch class set is that unique pitch class set within its equivalence class of pitch class sets such that this unique pitch class set contains the smallest sum of integers [1].

For example, the pitch class {2,3,4,5},{3,4,5,6}, {7,8,9,10},{0,1,2,3} are all equivalent but {0,1,2,3} produces the smallest sum of integers, so it is the prime form of this equivalence class of pitch sets.

The *complementary form* of a pitch class set is obtained through the process of *complementation*. To perform a complementation for a given pitch class set, simply form a set comprised of every pitch class which is not an element of the given pitch class set [1]. This new set is then the complement of the original pitch class set.

So, for instance, the complement of the pitch class set {1,3,5} is the pitch class set:

$$\{0,1,2,3,4,5,6,7,8,9,10,11\} - \{1,3,5\}$$
$$= \{0,2,4,6,7,8,9,10,11\}.$$

Although it may seem a somewhat baseless and directionless topic, the use of pitch class sets is actually quite important to composition and musical analysis from a mathematical point of view. What we have been calling pitch class sets are in actuality musical chords. Each pitch class set corresponds to one chord, and each pitch class set within an equivalence class of pitch class sets corresponds to the same chord [1].

However, due to the 12-tone nature of pitch class sets, within the set of all pitch class sets, each possible chord that can be formed out of 12 pitches is repeated 12 times, each one being a chord represented in a non-prime manner. Consequently, the set of all pitch class sets in prime form is isomorphic to the set of all possible chords in CMN.

As a result of this interesting fact, any operations, functions, transformations, etc. performed from, on or within the set of all pitch class sets can then also be performed from, on or within the set of all possible chords in 12-tone CMN. Pitch class sets can then also be utilized as a means of categorizing chords in a quantitative and qualitative manner, based on concepts such as the tonality of the chord, the consonance or dissonance of the chord, the size of the chord, etc.

Recall that music is notated on a five-bar staff, where key signature and time signature are notated and the staff is divided up into measures. As a result of this visual representation of music, visual symmetries can be achieved in music as well. We have already mentioned translation. Given a phrase in music, we can then translate a copy of that phrase to the beat onset immediately following the final beat of the musical phrase. We have then achieved translational symmetry within the sheet music, which can be continued on ad infinitum [1].

Inversion can be quantified as a type of symmetry in music as well, in the form of reflectional symmetry. However, other types of reflectional symmetries exist, too. On a small scale, a reflection across a certain staff line of the staff can be achieved by literally reflecting the musical phrase over the staff line [1].

A musical phrase can also be reflected with respect to a certain beat of the piece, which would have the effect of playing the phrase forwards and then immediately playing that same phrase in reverse. An arbitrary point on the physical page could also be selected as a point of reflection, although this is more often utilized in experimental pieces.

Musical rotation can be achieved as well, in addition to what has already been mentioned. Most often, this is achieved by selecting a certain beat and the pitch on said beat, i.e., a note, and rotating the phrase around the note by a certain number of angular degrees [1].

Taken all together, these musical visual symmetries form a number of dihedral groups which can be used during the composition process as a way of introducing repetition to a piece in an interesting manner, so as to keep the audience drawn into the piece at all times.

In the following sections, we will focus on a few more complex topics within the field of mathematics and music.

## Euclidean Rhythms

Recall that a rhythm is a pattern of beat onsets with specific durations. These onsets are interspersed among a total number of beats. A *Euclidean rhythm* is a rhythm such that its onsets are spread out among the total number of beats as uniformly as possible [4]. It should be noted that Euclidean rhythms are quite similar to a type of rhythm known as an *interlocking rhythm*.

To define an interlocking rhythm, we must first define the *complement* of a rhythm. Consider some arbitrary rhythm with a certain number of rest beats within it. That rhythm whose onsets occur on and cover the remaining beats of the initial rhythm is known as the complement of the initial rhythm [4]. So, an interlocking rhythm is a rhythm that, combined with its complement, completely covers the space of beats on which the rhythms take place. For example, a rhythm of four eighth notes, each on a main beat in a four-four time signature would have a complementary rhythm of itself translated over by one eighth note. Then, the two rhythms put together would result in a string of 8 eighth notes, completely covering the set of all beats that the rhythms take place on.

Oftentimes, a rhythm known as a *complementary interlocking rhythm* may form from an interlocking pair of rhythms. Disjoint and non-disjoint interlocking rhythms may also appear. *Disjoint interlocking rhythms* share no common onset [4]. A set of rhythms is denoted as *non-disjoint interlocking* if and only if every element of the set has at least half of its onsets as distinct.

A Euclidean rhythm is so named because the Euclidean algorithm for finding the greatest common divisor is actually isomorphic to an algorithm to produce maximally even rhythms [4].

There also exists a separate algorithm, known as the *Clough-Douthett algorithm*, which also produces Euclidean rhythms [4]. Let $E_{CD}(k,n)$ denote the Euclidean rhythm with $k$ onsets and $n$ pulses generated by the Clough-Douthett algorithm, where a pulse is one of the main beats in a measure as dictated by the time signature of the measure. The onsets of $E_{CD}(k,n)$ are then given by the sequence:

$$E_{CD}(k,n) = \{\lfloor {}^{in}/_{k} \rfloor : i = 0,1,...,k-1\}$$

Please see [4] for the explanation for the production of the sequence.

In addition to the Clough-Douthett algorithm and Euclidean algorithm, an algorithm known as *Bjorklund's algorithm* produces Euclidean rhythms as well [4].

As it so happens, the complement of a Euclidean rhythm is Euclidean up to a rotation [4]. To understand this, recall that a given rhythm can be translated by a number of beats. If we line the space of total beats, i.e. the pulses, up into a circle and place the rhythm on top of said circle, a translation of the rhythm is then simply a rotation. A rotation of a Euclidean rhythm is the same as a translation of the rhythm on top of the circle of oulses, and this rotation preserves the Euclidean properties of the rhythm.

Not only can a rhythm be rotated, it can be alternated as well. An *alternation* of a given rhythm is the transformation that keeps every cth onset of a rhythm, starting from some onset $j$ where $j \leq c \in \mathbb{N}$, while changing the rest of the onsets into rests [4]. So, when a given rhythm is alternated, a beginning section of the rhythm remains unchanged, after which a section of the rhythm is skipped over every certain number of beats.

Let $u_0, u_1, ..., u_{k-1}$ be the ordered sequence of the positions of the k onsets of a rhythm R, where $k \in \mathbb{N}$. Gómez-Martin, Taslakian and Toussaint [4] define the *j-alteration of order c* of R, denoted by $A_{j,c}(R)$, where $c \in \mathbb{Z}$, as the rhythm whose pulses are all rests except the onsets $\{u_j, u_{j+c}, u_{j+2c}, ..., u_{j+vc}\}$, where:

$$0 \leq j < c \leq k-1 \quad \text{and} \quad v = \lfloor {}^{k-1-j}/_{c} \rfloor.$$

According to Gómez-Martin, Taslakian, and Toussaint [4], a rhythm is Euclidean if and only if the clockwise distance of the ordered pair of onsets $(r_i, r_{i+1})$ is equal to either:

$$\lfloor {}^{ln}/_{k} \rfloor \quad \text{or} \quad \lceil {}^{ln}/_{k} \rceil \quad \text{for all} \quad l = 1,2,...,k \quad \text{and} \quad i = 0,1,..,k-1$$

In fact, the *j-alternation of order c* of any rotation of $E(ck,n)$ is Euclidean for $c > 1$, where $E(ck,n)$ denotes a Euclidean rhythm produced by the Bjorklund algorithm. For the proof, see [4].

Euclidean are quite interesting and important for a few reasons. First, they serve as an excellent example of combinatorial mathematics interconnected within rhythmic music. Next, they are quite easy to produce using the aforemntioned algorithms, and thus are used widely within the musical industry. Lastly, another reason for their wide spread use is because of the way a Euclidean rhythm is able to evenly break up measures of some number of pulses in a way that is non-standard, i.e., not simply counting off beats. Additionally, the interlocking qualities of Euclidean rhythms and their complements allow for ease of fulfilling musical space with onsets.

## 12-tone Matrices

*Atonal music* is music composed with the goal of having no pitch center [3]. In other words, the music is composed in such a way as to forego the use of a key signature. Several methods exist for composing atonal music, with one of the most popular methods being the use of a 12-tone matrix.

A 12-tone *matrix* is created using the properties of *12-tone rows*, where a 12-tone row is a sequence of 12 distinct pitches [7]. To create a 12-tone row, we first designate a note class for one of the 12 notes. Then, from the remaining notes, we find each of the remaining note classes within the row. We accomplish this by using each individual note class's modular chromatic interval with respect to the initial note.

In other words, we list out a sequence of length 12 comprised of the distinct elements of $\mathbb{Z}_{12}$. However, the first entry in the sequence, i.e., the first note in the sequence, should always be 0 mod 12. For now, let us work with the following sequence used in [7]:

[0] [3] [2] [5] [4] [8] [1] [10] [11] [9] [7] [6]

Now, we begin the construction of the matrix. We number the rows and columns of our matrix by the integers 1 through 12, letting the ordered pair $(i,j)$ denote the entry at row $i$ and column $j$, where $1 \le i, j \le 12$. The first row of the matrix will be our original 12-tone row [7].

Hence, our first row will be:

$a_1 = [0]$  $a_2 = [3]$  $a_3 = [2]$  $a_4 = [5]$  $a_5 = [4]$  $a_6 = [8]$

$a_7 = [1]$  $a_8 = [10]$  $a_9 = [11]$  $a_{10} = [9]$  $a_{11} = [7]$  $a_{12} = [6]$

Then, the first column will list out the inverses of our original 12-tone row in Z_12:

$-a_1 = [0]$  $-a_2 = [9]$  $-a_3 = [10]$  $-a_4 = [7]$  $-a_5 = [8]$  $-a_6 = [4]$

$-a_7 = [11]$  $-a_8 = [2]$  $-a_9 = [1]$  $-a_{10} = [3]$  $-a_{11} = [5]$  $-a_{12} = [6]$

Next, we fill in the rest of the entries in the matrix. For the entry in the $(i,j)$ position, when added with the leftmost entry in the $i$-th row, which is $-a_i$, the entry in the $(i,j)$ position should form the interval $a_j$. Consequently, the entry in the $(i,j)$ position should be $a_j - a_i$ mod 12 [7]. For example, the entry in position:

$$(8,5) \text{ is } a_5 - a_8 = [4] - [10] = [6]$$

Our final 12×12 matrix is given in *Table 10* [7]:

**Table 10:** Example 12-tone Matrix. Courtesy of David Wright, 2009 [7].

| 0 | 3 | 2 | 5 | 4 | 8 | 1 | 10 | 11 | 9 | 7 | 6 |
|---|---|---|---|---|---|---|----|----|---|---|---|
| 9 | 0 | 11 | 2 | 1 | 5 | 10 | 7 | 8 | 6 | 4 | 3 |
| 10 | 1 | 0 | 3 | 2 | 6 | 11 | 8 | 9 | 7 | 5 | 4 |
| 7 | 10 | 9 | 0 | 11 | 3 | 8 | 5 | 6 | 4 | 2 | 1 |
| 8 | 11 | 10 | 1 | 0 | 4 | 9 | 6 | 7 | 5 | 3 | 2 |
| 4 | 7 | 6 | 9 | 8 | 0 | 5 | 2 | 3 | 1 | 11 | 10 |
| 11 | 2 | 1 | 4 | 3 | 7 | 0 | 9 | 10 | 8 | 6 | 5 |
| 2 | 5 | 4 | 7 | 6 | 10 | 3 | 0 | 1 | 11 | 9 | 8 |
| 1 | 4 | 3 | 6 | 5 | 9 | 2 | 11 | 0 | 10 | 8 | 7 |
| 3 | 6 | 5 | 8 | 7 | 11 | 4 | 1 | 2 | 0 | 10 | 9 |
| 5 | 8 | 7 | 10 | 9 | 1 | 6 | 3 | 4 | 2 | 0 | 11 |
| 6 | 9 | 8 | 10 | 11 | 2 | 7 | 4 | 5 | 3 | 1 | 0 |

A composition can then be made using the entries within the matrix. Most commonly, a composition of 12 measures consisting of 12 beats will be created, with the nth measure consisting of the notes in the nth row of the matrix. However, other variations can be created, such as adding more complicated rhythms or utilising different rows, columns, or entries. Regardless, utilization of the entries within the matrix will result in the production of music that is atonal.

Additionally, a matrix need not be based only on 12-tones. In fact, any number of tones can be chosen [7]. To form an n-tone matrix of size $n \times n$, first begin with an original row:

$$a_1, a_2, ..., a_k, ..., a_n$$

where $n \in \mathbb{N}$, $a_k \in \mathbb{Z}_n$, and $1 \le k \le n$

This original row will be row 1 of the matrix. Then, we construct the additional entries within the matrix by the following rule:

$$\text{entry}(i,j) = a_j - a_i$$

The rows of a given $n$-tone matrix possess certain properties. Obviously, a row is made up of $n$-distinct entries. Given an original row in a matrix, denoted as its prime form $P$, it is permissible to use its inversion, denoted $I$ its retrograde, denoted $R$, or its retrograde inversion, denoted $RI$, within the matrix. Additionally, its transposition $T_j$, where $j \in \mathbb{Z}_n$, can be utilized as well. These preserve the intervals found within the original row.

When reading a matrix, reading a row from left to right gives a prime form, while reading a row from right to left gives its retrograde form. Reading a column from top down produces an inversion form, while reading a column from down up produces a retrograde inversion form. Lastly, it should be noted that an $n$-tone matrix will always have a diagonal of identical entries.

## Bell-Ringing

*Change-ringing* is music involving the use of tower bells, the type of bells you would usually find in church towers. This style of music has existed for centuries, first emerging in England around the 1700's [3]. At this time, ringing loud tower bells was the best way to notify people of the passage of time and for things such as the beginning of religious services. Over the course of the centuries, it has continued to evolve into a musical style with intrinsic connection to mathematical group theory.

The foundation of change-ringing is based upon the time needed for bells to fully complete a cycle of hitting a note. Tower bells can weigh well over two tons. In order for a bell to ring, it must be put into a swinging state, and once it is in this state, it is difficult, if not impossible, to immediately stop the swinging [3]. Additionally, once a bell hits its note, it takes a few seconds for the note to ring again, due to the slow swinging motion of the bell. So, in order to fill the empty space between onsets of the bell note, multiple bells are utilized, typically around 3 to 8 different bells, although some towers have up to 14 different bells.

For a set of $n$ distinct bells, each bell is denoted one of $1, 2, \ldots n$, where the highest pitched bell is denoted 1, the next highest is denoted 2, and so forth, until the lowest bell, the tenor, is denoted $n$, where $n \in \mathbb{N}$ [3].

Because of the amount of time required between successive rings of the same bell, change-ringing is organized into rows of sequences of the $n$ bells, with each bell appearing once in the sequence [3]. This sequence is denoted as a change. Without any outside influence, once a change has rung, it will repeat itself some number of times, up until the bells have ceased to swing. Typically, a conductor will signal a change to occur between each sequence, hence the name change.

However, certain restrictions apply to the types of changes that can occur between each change. Namely, only adjacent positions can be swapped between each change, due to the rate of bell ringing [1].

To see why this is necessary, consider the following incorrect change sequence:

1452332521

In order to perform this sequence, bell 3 would need to ring twice in a row, as it has been swapped with bell 1. Thus, a pause of two seconds, at least, would need to be included in any performance, which can be quite jarring to an audience. Yet, bell 1 is both beginning and ending the sequence, which requires that the entire sequence be performed in approximately two seconds, contradicting our previous statement. Consequently, this sequence cannot be performed.

A correct change sequence would be the following:

1452315432

Let us denote the general positions of bells within a sequence by labelling each position:

$$A, B, C, \ldots$$

from left to right. Then, we can define a function between two successive change rows by a series of permutations $(AB), (AC)$, etc [5].

A typical piece for change-ringing is known as an extant [5]. For an extant on n bells, where $n \in \mathbb{N}$, the extant begins and ends with the sequence of length n, while in between, every distinct sequence of length n, aside from the beginning sequence, is played exactly once.

For three bells, we have $3 \times 2 \times 1 = 6$ possible changes, since there are three bells that could appear in position $A$, then two bells that could appear in position $B$, and lastly, one bell that can appear in position $c$, for a given change. For four bells, we have $4 \times 3 \times 2 \times 1 = 24$ possible changes. For five bells, we have $5 \times 4 \times 3 \times 2 \times 1 = 120$ possible changes. Hopefully this pattern appears familiar to you, as it is describing the factorial function. So, for a set of n distinct bells, we have n! possible distinct changes [5].

Interestingly enough, the set of changes on $n$ bells actually forms a group under permutations that is isomorphic to the symmetric group $S_n$, where $n \in \mathbb{N}$. Hence, performing an extent is actually isomorphic to performing a walk around the corresponding symmetric group, i.e., beginning on an arbitrary entry in the symmetric group, subsequently playing every other distincti entry of the symmetric group, and then ending on the beginning entry. However, it is quite noteworthy that techniques involved in composing extents actually came about a few centuries before the foundations of mathematical group theory were set in place [3].

## Conclusion

In this article, we covered significant topics within the field of mathematics and music. This article provides a basic overview of the relation between mathematics and music as well as some more complex connections within the field. It gives the reader a basic understanding of the mathematics that can be found within music and points to some exciting mathematical structures found within music. The physical properties of sound waves were explored, and musical notation and melodic transformations were detailed. Scale construction and tuning systems were introduced. Lastly, an overview of a few interesting topics within the field was presented, including an overview of Euclidean rhythms, change-ringing and 12-tone and n-tone matrices.

We explored some of the connections between group theory and music, as well as a tiny bit of set theory and Fourier analysis. However, connections between music and mathematical graph theory, linear algebra and number theory exist as well, among others. These would be interesting connections to explore in the future.

## Acknowledgements

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# The Role of Propionate during the Interactions of Macrophages and *Listeria monocytogenes*

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## Abstract

Macrophages are a type of innate immune cells that are critical in helping us fight off infections both by directly targeting invading pathogens and by eliciting adaptive immune responses. Therefore, it is important to study how the environmental conditions, such as chemical signals present in the body, affect macrophage activities. In my thesis research, I aim to identify how different physiologically relevant chemical signals, such as propionate or antibiotics, affect macrophage functions in immune defenses against a foodborne pathogen, *Listeria monocytogenes*. In this article, I aim to describe the background information and the current literature to support my research endeavor. Finally, I discuss the research questions I plan to address through further experimental research.

## What Are Macrophages? What Kinds of Cells Are They?

Macrophages are white blood cells involved in innate immunity. Being a part of the innate immune system, they can respond to a variety of pathogens by recognizing general features of the pathogens. This is opposed to the cells of the adaptive immune system, which exhibit pathogen-specific responses. Macrophages are also well known as effector cells, meaning they can directly target pathogens to defend their host.[1]

Macrophages differentiate from monocytes, which are created in the bone marrow through the process of hematopoiesis. As monocytes enter and circulate the bloodstream, they may enter tissues, initiating differentiation into either macrophages or dendritic cells.[2] Although most of the macrophages in the body are formed through this process, macrophages may also originate from the yolk sac during fetal development. These account for many of the macrophages found in tissue.[3] Throughout the body, different tissues contain resident macrophages that function there. These macrophages take on unique roles depending on their location in the body, developing different "chromatin landscapes" in different tissues.[2] Although they become tissue-specific, macrophages are still able to function properly when entering a new tissue by adjusting gene expression.

## What Do Macrophages Do?

In addition to their well-known functions in the immune system, macrophages are also involved in other processes such as the maintenance of homeostasis. In most tissues, macrophages do this by preventing the accumulation of waste materials from apoptotic and dead cells by digesting them. In the liver and spleen, this digestion is particularly important because it enables significant iron recycling.[3] Their ability to digest waste and dead cells has made them crucial in many processes, such as tissue

regeneration, metabolic homeostasis, bone remodeling and even thermogenesis.[2] Despite their involvement in various processes, macrophages are most well known for their role in the immune system.

Elimination of cellular waste and dead cells are some of the major functions of macrophages. Resident tissue macrophages do this by digesting apoptotic cells and waste material through phagocytosis. In this process, the macrophages avoid inflammatory response and activation by taking up signal molecules like TGF-β, IL-10 and PGE2.[2] These signal molecules allow them to regulate waste and clean up dead cells within the body while suppressing an active immune response.

Another major function of macrophages is to engulf pathogens. Macrophages have receptors on their cytoplasmic membrane that bind to specific signal molecules in the surrounding area. When a macrophage detects a molecule that it recognizes as foreign, it engulfs it through phagocytosis. The ability of macrophages to digest pathogens through phagocytosis is what makes them known as effector cells. They are able to directly kill bacteria. Unlike the digestion of dead cells and wastes, the digestion of pathogens does trigger an immune response.

The final major role of macrophages is to initiate an elevated immune response any time a pathogen is detected. This is accomplished through secretion of various cytokines. A cytokine is a molecule that communicates a specific message to surrounding cells. Cytokines such as IL-1 beta and TNF-alpha increase permeability and flow of vascular endothelium.[4] This increases the flow of leukocytes from the blood, enabling them to reach the site of macrophage activation. These cytokines also allow for more drainage of fluids to lymph nodes.

For other leukocytes to reach the site of macrophage activation, they must also be able to find the site in the body. A type of cytokine known as a chemokine is responsible for recruiting other leukocytes to the correct tissue. When macrophages secrete chemokines, it creates a gradient of molecules that leukocytes can bind to, inducing a form of cell motility known as chemotaxis.[4] This enables leukocytes to continue binding to chemokines as they migrate closer to the site where the chemokines were released. Other cytokines may increase the expression of receptors on the surface of nearby endothelium

lining blood vessels. These receptors bind to proteins on the surface of white blood cells, signaling them to cross the blood vessel and enter the area that triggered the immune response.[4] Overall, the systematic effects of elevated immune response due to macrophages are fever and inflammation, as white blood cells are recruited to the site of injury or pathogen.

## How Are Macrophages Activated? How Are Macrophages Different Functionally When They Are Activated?

There are two main pathways for macrophage activation. Classical activation occurs when macrophages come into contact with a pathogen or cytokine. One of the major ways in which macrophages recognize pathogens is through Toll-like Receptors (TLRs). Macrophages, as well as dendritic cells and neutrophils, have these TLRs on their cell membrane surface that recognize patterns of molecules typically displayed on bacteria, called pathogen-associated molecular patterns (PAMPs). This can include molecules present on bacterial flagella and on their peptidoglycan cell wall, such as lipopolysaccharides.[5] TLRs may also recognize molecules that are typically displayed by human cells that have been damaged. Once TLRs recognize a pathogen, transcription factors involved in the expression of cytokines, enzymes, and other antimicrobial proteins are signaled to respond.[5]

Classical activation also occurs when macrophages come in contact with IFN-gamma. This is a type of cytokine that is secreted from other cells that have encountered a pathogen. This cytokine can be produced in innate and adaptive immune responses. Activation through IFN-gamma induces the same response as activation through TLRs. The macrophages have increased expression of cytokines, enzymes and antimicrobial proteins. Classically activated macrophages involving TLRs and IFN-gamma are known as M1.[5]

Alternative activation, also known as M2, occurs when macrophages are responding to wounds. The main signal molecules that trigger M2 activation are interleukin-13 and interleukin-4.[5] These signals enable macrophages to produce growth factors that promote healing.[6] M2 activation is also characterized by

anti-inflammatory effects to promote wound repair. Because my research focuses mainly on the antimicrobial functions of macrophages, I will describe the pro-inflammatory activities of macrophages in this literature review.

Once classical activation is initiated by IFN-gamma or a pathogen, several specific changes occur to prepare lysosomes. Lysosomes are vacuoles that contain many toxic compounds capable of killing bacteria. In response to activation, the components of NADPH oxidase shift, to become functional. This increases the oxygen intake of the cell. Through several enzymatically catalyzed reactions within the lysosome, toxic reactive oxygen species (ROS) are produced.[4] Therefore, activated cells have an increase in ROS production. ROSs are one way that bacterial cells can be degraded within the phagolysosome. In addition, activation causes an increased production of lysosomal proteases and lipases. These enzymes are able to cleave amino acids and lipids, respectively. Nitric oxide is another molecule that is present in much higher concentrations during the activated state. It has been observed to have an increased presence during an infection or inflammation.[7] Lastly, an increase in production of antimicrobial peptides (AMPs) is detected during the state of activation. Overall, classical activation causes increases in the antimicrobial activity of macrophages.

## What Is Phagocytosis?
## How is the Process Taking Place?
## What Happens after Phagocytosis?

Phagocytosis is the main way in which macrophages act to directly kill foreign pathogens. The first step of phagocytosis is recognition of PAMPs by TLRs and some G-protein coupled receptors.[8] Other signals that can trigger phagocytosis are opsonins. These molecules are found on antibodies that have caused opsonization of a pathogen. Opsonization is one way in which the adaptive immune system targets a specific bacteria and causes it to aggregate together so that it can be phagocytized by cells of the innate immune system.[9] The final type of signal that can trigger phagocytosis are signals displayed by apoptotic cells. The signals that trigger phagocytosis cause many interactions within the cell to take place.[8] These interactions are specific to what type of signal is recognized, but ultimately lead to changes in gene expression, inducing the cell to begin ingesting the particle.

Ingestion of the foreign or apoptotic cell is the next step of phagocytosis. This involves polymerization and depolymerization of the actin cytoskeleton. In this process, two pseudopodia protrude and extend around the target particle, eventually surrounding it. To close the extension and form the phagosome, the actin cytoskeleton is eliminated at the ends of the two pseudopodia.[8]
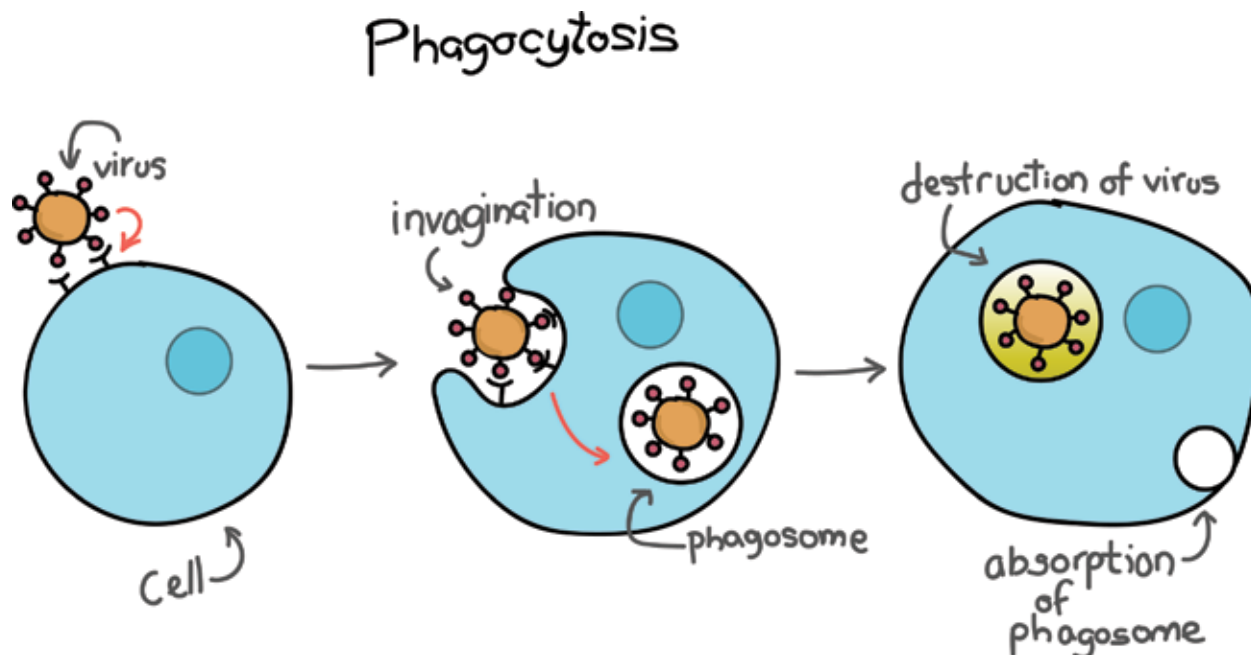


**Figure 1.**[10] In this example, phagocytosis of a virus is triggered by a protein on the surface of the virus interacting with a receptor on the surface of a macrophage. Courtesy of Khan Academy website, accessed August 2019.

After ingestion, the phagosome fuses with a lysosome to create a phagolysosome. The lysosome contains all the hydrolytic enzymes and antimicrobial molecules that were described earlier, such as nitric oxide, ROS, proteases, lipases, and AMPs. The lysosome is also characterized by its low pH, which can become as low as 4.5. This low pH can be damaging to many pathogens. Lysosomes are present in the cytoplasm of phagocytic cells and are present in higher concentrations when a macrophage is activated. Once the phagosome fuses with the lysosome, the pathogen is exposed to these toxic particles and begin to degrade. Once the bacteria is broken down, it is excreted as waste.[8]

## How Do Macrophages Interact with *Listeria*?

The focus of this research is on the intracellular, foodborne pathogen, *Listeria monocytogenes*. *Listeria* can enter a host cell in two ways. The first way it can enter is through active invasion. There are several proteins that enable *Listeria* to do this. One of these is internalin, which is a protein that extends from the bacterial cell wall. It can interact with E-cadherins, a type of adhesion molecule on the outside of host cells.[11] This allows the bacteria to stick to the host cell. Other cell proteins have also been shown to be crucial in the invasion of *Listeria* into macrophages. Studies have shown that an enzymatic virulence factor known as P60 interacts with internalin to support the uptake of *Listeria* by nonphagocytic means.[12] Once *Listeria* enters through an invasive route, it becomes located in the cytoplasm, where it can begin to grow.

The second way in which *Listeria* is able to enter macrophages is through phagocytosis. This occurs how it would with any other pathogen that macrophages recognize. Once detected, the macrophage attempts to phagocytose and digest the *Listeria* in the phagolysosome. Under normal circumstances, macrophages are effective in killing off *Listeria* that enter through phagocytosis. This is supported by experiments on mice, that determined the lethal dose to be relatively high (LD50).[13] This is due to the success of the antimicrobial activity occurring in phagolysosomes.

However, *Listeria* produce virulence factors that enable it to escape the phagosome so that it can grow in the cytosol. One of the most significant virulence factors is listeriolysin O (LLO), encoded by the hly gene. LLO is a pore forming toxin that allows *Listeria* to escape the phagosome. *Listeria* can begin to penetrate and escape the phagosome approximately 30 minutes post infection because of LLO. Without the hly gene, *Listeria* is unable to escape the phagosome and grow, and is ultimately killed by the host cell.[14] Therefore, LLO is a necessary virulence factor for *Listeria* survival and growth inside macrophages.

## How Does *Listeria* Establish Itself as a Human Pathogen?
## How Important Is Knowing More about *Listeria*?
## How Are *Listeria* Infections Treated?

It is important to study *Listeria* so that we can better treat listeriosis, a disease associated with the septic infection of *Listeria*. The CDC estimates that each year, approximately 1,600 people in the United States become sick from *Listeria*, and about 260 of those people die.[15] Most individuals who are infected with listeriosis are immunocompromised, pregnant, or elderly. Pregnant women are 10 times more likely than the rest of the population to get listeriosis.[16] The incidence rate for these susceptible groups of people is alarming. Therefore, the interactions of *Listeria* with the immune defenses are important to understand so that we can determine ways in which our body can help prevent the onset of this disease.

*Listeria* is also an important pathogen to study because it provides a model for several other types of pathogens, allowing us to better understand many different aspects of pathogenesis. As a model for an intracellular pathogen, it can inform us about the mechanisms that bacteria can use to reside within our own cells, shielded from many cells of our immune system and antibiotics. As a foodborne pathogen, it enables us to learn more about how bacteria can survive under harsh growing conditions, and how it may respond once introduced to host cells.

A person can contract *Listeria* by ingesting contaminated food. The highest risk of contamination is in dairy products and lunch meats. After ingestion, *Listeria* migrates with the food to the

intestines, where it can come into contact with the intestinal tissue, the innate immune cells of the gastrointestinal tract, and other chemicals present in this tract. It can infect phagocytic cells by being phagocytosed or it can invade cells using virulence factors. In rare cases, it can then spread to the blood and peripheral organs, causing listeriosis. In healthy individuals, it typically causes symptoms similar to food poisoning, which generally does not develop into a serious infection. Although it can cause disease in many individuals, the CDC found that about 5 percent of an unselected population had *Listeria* in their stool.[17] This means that *Listeria* can even be present within individuals, and not grow enough to become symptomatic.

When an individual presents symptoms of food poisoning during *Listeria* infection, they are likely to be tested for different infections through various blood and fluid samples. In the meantime, they may be prescribed antibiotics like ampicillin or amoxicillin if deemed necessary. If results indicate that the pathogen is *Listeria*, ampicillin and gentamicin are usually the first line of antibiotics prescribed.[17] *Listeria* is not typically thought of as an antibiotic resistant pathogen. In a study conducted on human isolates from France, it was found that only 1.27 percent of *Listeria* were resistant to a clinically relevant antibiotic.[18] However, resistance to tetracyclines and fluoroquinolones was recently reported, raising the concern for the emergence of resistance to these types of antibiotics.

## What are Short-chain Fatty Acids? How Are They Produced?

To consider the signals present during *Listeria* transit through the intestinal tract and interaction with macrophages, I will describe the molecules Short Chain Fatty Acids (SCFAs). SCFAs are carboxylic acids containing two to six carbons. Anaerobic bacteria in the gut produce short chain fatty acids as a byproduct of the metabolism of high-fiber foods. The three dominant SCFAs produced by bacteria in the gut are acetate, butyrate and propionate. In the colon, these are found in concentrations of approximately 60 percent acetate, 25 percent propionate, and 15 percent butyrate.[19] Although they originate in the gut, SCFAs can cross endothelial layers and be found in the bloodstream and other tissues at a lower level.

SCFAs, and their interactions with the gut microbiota have recently come to the forefront of research since they have been shown to be involved in many processes in the body, and have an impact on several aspects of human health. Studies have indicated that SCFAs can activate specific receptors on the cells in the liver, pancreas, adipose tissue and brain, allowing for communication regarding glucose levels in the body. One study found that SCFAs have an impact on diabetes by regulating glucose homeostasis through interactions with the pancreas.[20] Another study found correlations between the concentrations of SCFAs found in colonic bile and risk for cancer.[21] Propionate has even been shown to have impacts on the behaviors of mice, causing reduced social interaction, increased anxiety-related behavior and hypoactivity.[22] SCFAs are being studied in a wide range of physiological and psychological areas, and have been shown to interact with the body in numerous ways.
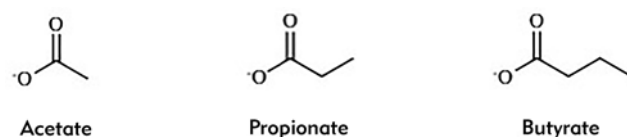


**Figure 2.** The dominant short chain fatty acids found in the gastrointestinal tract. These are present in different concentration. In the stool samples acetate had a prevalence of 60% acetate, 25% propionate, and 15% butyrate. Courtesy of Stephanie Johnson (ChemDraw), 2019.

## What are Known Effects of Short-chain Fatty Acids on Macrophages?

Recently, many studies have examined the effects that SCFAs have on white blood cells. This is an interesting topic of study because leukocytes can be found in the endothelial lining of the intestines and colon, surrounded by a large population of microbes, without triggering an elevated immune response. Several studies have actually determined that butyrate, one of the SCFAs, induces a heightened level of activity for macrophages. Specifically, butyrate induced differentiation of monocytes into macrophages. In addition, treatment of macrophages with butyrate caused an increase in resistance to several pathogens commonly found in the gastrointestinal tract by upregulating the production of antimicrobial peptides.[23]

Other studies found that short chain fatty acids have anti-inflammatory effects. Mice that were orally supplemented with butyrate for five days and then infected with *Salmonella enterica* or *Citrobacter rodentium* showed no inflammation in the gastrointestinal tract, whereas mice that were not supplemented with butyrate experienced mild gastrointestinal inflammation.[24] This is supported by another study that indicated that propionate and butyrate caused downregulation of TNF-a, IL-1b, and IL-6, a group of proinflammatory cytokines that may be released by macrophages.[25] Therefore, the presence of SCFAs like propionate and butyrate may help inhibit a proinflammatory response to pathogens within the gut.

Many studies have also tried to examine which specific receptors and signals may be impacted by the interactions between SCFAs and macrophages. It has been determined that interactions between SCFAs, and TLRs and G-protein coupled receptors are not responsible for the increased bactericidal behavior of macrophages. However, there is an impact on histone deacetylases.[26] Histone deacetylases are enzymes that remove acetyl groups from histones, proteins that help to coil and organize DNA. When this occurs, intermolecular bonding becomes stronger due to an increase in charge, causing the DNA to become inaccessible. One study concluded that transcription of genes encoding for NO production and cytokine production was reduced in macrophages supplemented with propionate and butyrate in the pancreas.[27] Therefore, another way in which SCFAs impact macrophages is through suppression of proinflammatory genes.

## How Do Short-chain Fatty Acids Affect *Listeria*?

The study of the effects of SCFAs on *Listeria* is a new area of research. Research conducted in my lab suggests that propionate can alter the growth of planktonic and sessile *Listeria* in varying ways. In addition, propionate treatment resulted in altered concentrations of ethanol, acetoin, and lactate, which are all byproducts of carbon metabolism.[28] These results indicate that the presence of propionate may effect carbon metabolism of *Listeria*.

Most significant to my research were the findings regarding LLO production. LLOs are virulence factors that help *Listeria* escape the phagosome. It was found that under aerobic conditions, LLO concentrations found in the supernatant were significantly lower for *Listeria* treated with propionate.[28] This means that the presence of propionate decreased virulence under aerobic conditions. In contrast, under anaerobic conditions, LLO concentrations found in the supernatant were significantly higher for *Listeria* treated with propionate. These results indicate that the presence of propionate increased the virulence of *Listeria* under anaerobic conditions.

## Main Research Questions

The interactions between macrophages and *Listeria* in the presence of propionate is an area of research that is practically uncharted. However, these interactions are necessary to understand due to their clinical implications. Studies have shown that resident macrophages in the gut act differently from macrophages in other tissues. They are typically characterized as highly active, but not pro-inflammatory.[29] I hope to discover whether the presence of SCFAs, which are found in high concentrations in the gut, may promote the unique behavior of macrophages in the gastrointestinal tract. I aim to research the effects of propionate during the interactions of *Listeria* and macrophages to determine whether propionate affects pathogenesis in a way that affects the onset of infection. I plan, and have begun to, accomplish this by studying the following questions.

### How Do Short-chain Fatty Acids Affect Macrophage Nitric Oxide Production?

Nitric oxide (NO) production is an indication of antimicrobial activity of macrophages. To determine NO production, I use a nitric oxide assay of activated macrophages with varying concentrations of propionate. A high NO production indicates high antimicrobial activity of macrophages. This would suggest an elevated immune response, which could be beneficial in fighting off infection.

## How Do Short-chain Fatty Acids Affect Phagocytic Activity?

Phagocytic activity is also an indication of antimicrobial activity. To determine phagocytic activity, I use a phagocytosis assay with pre-treatment of macrophages with propionate. Fluorescent dead E.coli particles are added to the macrophages so that fluorescence can be used as a measure of phagocytic activity. A high phagocytic activity, or high fluorescence would indicate an elevated immune response.

## How Do Short-chain Fatty Acids Affect Intracellular growth of *Listeria*?

Intracellular growth of *Listeria* can be determined through gentamicin protection assays. In this assay, macrophages which may or may not have a propionate pre-treatment is infected with *Listeria* that may or may not have a propionate treatment. Intracellular growth is an indication of infection progress. A higher intracellular growth would indicate a less bactericidal macrophage.

## Future Research

My specific interests in this research lies in identifying ways in which our body reacts to infection and ways in which our body works to prevent it. I hope to research this more in the future so that disease treatment and prevention can be optimized. Antibiotics, the major treatment for infectious diseases, are typically tested in a laboratory setting on bacteria in growth medium. These growing conditions are dissimilar to how pathogens grow in the body, and it does not account for the interactions the body might have with the pathogen, fluids, or the antibiotic prescribed. Therefore, I hope to identify more ways in which the body interacts with infection and treatment.

In future research, I hope to test other SCFAs, rather than only using propionate, and simulate the concentrations of SCFAs found in the gut. This would include NO assays, phagocytosis assays, and gentamicin protection assays. I also hope to test the effects of antibiotics on macrophage cells because recent research suggests that antibiotics may have an effect on human cells. I hope to test phagocytic activity and NO production of macrophages that were grown in concentrations of antibiotics like tetracycline. Tetracycline targets the RNA polymerase of bacteria, however it has been suspected that it can also have an effect on human mitochondrial RNA polymerase, which has a similar structure to that of bacteria.

In conclusion, I hope to conduct research to increase our understanding of the ways in which pathogens interact with the body. By increasing our understanding in this area of study, we can improve methods for disease prevention and treatment.

## Acknowledgements

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# Impact of Parental Involvement in the Use of Adaptive Number eBook Technology in Preschoolers: A Review

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## Abstract

Many students in the United States are not performing at a desired level of proficiency in mathematics A child's education in mathematics begins at a very young age. One method by which children are introduced to the basic concepts of math is number books. Traditional number books have been found to be successful in promoting mathematical knowledge but are stagnant in their difficulty, leaving parents to discern ambiguously when their child is ready to move onto more difficult problem-solving. The present study seeks to discern the effectiveness of new eBook technology as well as the impact parents have on their children's ability to learn. Specifically, there is hope that the design and adaptive nature of electronic learning will help promote parent-child conversation around the topic of mathematics.

## Literature Review

Math and the skills surrounding it are crucial and beginning in preschool; they predict both later math and career success (Bull, Espy, & Wiebe, 2008; Clements, Sarama, & Germeroth, 2016), as well as later reading performance (Duncan, et al., 2007). Therefore, with four in ten children failing to reach the mark of basic proficiency in math by the time they reach fourth grade (National Assessment of Educational Progress, 2017), there is an urgency to improve abilities in mathematics, especially with the rapid growth of STEM occupations over the past decade (Bureau of Labor Statistics, 2017). These gaps in ability begin to emerge in early childhood, often before children enter the education system (Dowker, 2008). Additionally, children who start behind in math often stay behind throughout their academic careers (Bailey, Siegler, & Geary, 2014; Siegler et al., 2012). This evidence shows that a child's activities at home are a crucial part of the beginning of the development of math skill. This review examines how the existing literature on parent child interaction, technology and development of cognitive processes can inform the design and structure of an adaptive eBook meant to improve children's abilities with mathematics.

The development of a child's ability in mathematics has many components. One predominant array of skills are Executive Functioning skills. Executive function EF skills have been proposed as an important piece of the cognitive puzzle that leads toward success in mathematics, as well as being undeveloped in children who are at risk for developing math learning disabilities. EF is the management of thought processes, primarily inhibition, working memory and shifting, described in more detail below (Zelazo, Mueller, Frye, & Markovitch, 2003). EF has been linked to advancements

in problem-solving as well as flexible thinking when new situations arise (Cragg & Gilmore, 2014). Notably, EF skills, specifically cool EF skills, are correlated with growth in math skills in early childhood (McClelland et al., 2007; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009). How EF leads to better math skills can be found in any preschool classroom. Take for example a task that asks a child to count the total of each type of barn animal in a picture. A child would have to remember the problem they are trying to solve, holding the instructions in their working memory, mentally separate the different animals into categories, shift between those categories as they count, and



**Figure 1.** Example of possible design for pages that challenge inhibition. Courtesy of Patrick Ehrman (open source images), 2019.

inhibit classroom noise while carrying out the assignment. These skills also apply to problems based on comparison quantities sch as a task that asks children to choose which person is holding more pencils. Children living in poverty, as well as those vulnerable to math learning disabilities have particular difficulty with executive function skills (Geary et al., 2007).
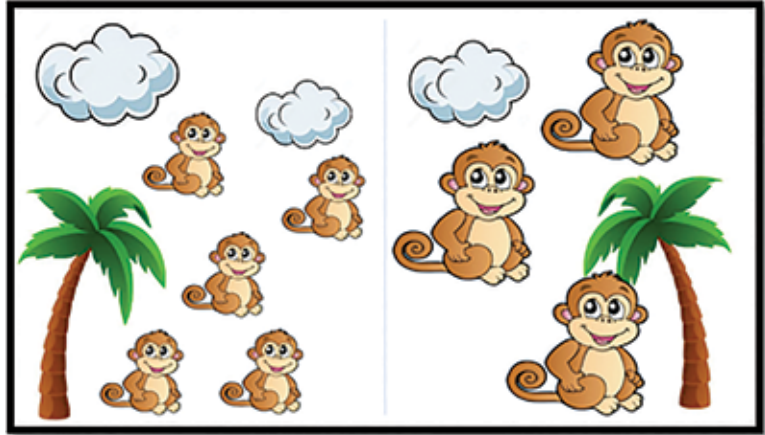
Training EF would involve training in each of the sub-processes that it regulates. Colloquially known as self-control, inhibition is the ability to minimize distractions from one's environment as well as undesirable actions from one's self (Cragg & Gilmore, 2014). An example of inhibition would be a child ignoring the images of trees and clouds that make up the background of a scene in a book in order to count the number of animals they see. *Figure 1* illustrates this concept. The information of trees and clouds must be inhibited in order to include only the monkeys when discerning quantity. Job, Friese and Bernecker (2016) show that training in skills associated with inhibition can boost grade point averages, as well as increasing time spent on academic tasks. Working memory is the ability to monitor and manipulate information for short durations without external assistance (Alloway, Gathercole, & Pickering, 2006; Huizinga et al., 2006). Much of the development associated with working memory takes place throughout the preschool years, with children reaching kindergarten able to manage complex tasks (Gathercole et al., 2004). However, this development does not take place in a vacuum. Garon et al. (2008) and Simpson and Riggs (2005) both affirm that inhibition's relationship with working memory can place stress on the working memory, especially during complicated tasks. Young children in particular have difficulty with tasks that involve both the functions of inhibition and working memory (Carlson, 2005). Shifting is the ability to move from one task to a different task (Cragg & Gilmore, 2014). This involves the capacity to change rulesets, thought processes and various tasks. Pre-schoolers are on average able to shift between two tasks when they are presented in the context of a story (Hughes, 1998). Evidence suggests that shifting may be the slowest developing of the three sub-processes, leading to the belief that a combination of inhibition and working memory are required in order to change between tasks (Garon et al., 2008). Shifting skills have been found to higher academic performance. Yeniad et al. (2013) in their meta-analysis provide evidence that indicates greater ability to shift successfully is associated with higher scores on math tests.

While EF training is a promising avenue for developing math skills, there are limitations. Melby-Lervag and Hulme (2013) found that across 23 studies on both adults and children working memory training produced only a short-term effect on performance, and that the effect was not generalizable. To contradict Melby-Lervag and Hulme, Thorell et al. (2008) found that working memory training in preschoolers resulted in better performance in both spatial and verbal performance. Importantly, the training generalized to problem solving tasks. These increases in performance persisted three months after the conclusion of the study. Since there is some concern on the usefulness of training

of EF skills, on possible alternative is to embed the training into math practice and activities. Games and play that are oriented towards enhancing math skills have promising positive results in their ability to promote broad mathematic ability (Scalise, Daubert, & Ramani, 2017; Ramani & Scalise, 2018).

Beyond executive function skills, there is clear evidence that the practice of caregivers reading number books with their child leads to an improvement of math skills (Purpura et al., 2017). In conjunction with reading, the frequency with which parents use math-oriented language is also linked with the advancement of math skills. Gunderson & Levine (2011) found that number talk at home predicts future cardinal-number skills. The diversity of the number talk used in the home is also important. Children who are exposed to language that is predominantly of one type, such as small number talk (talk ranging from the numbers 1-3) may fall behind children exposed to a more diverse range of topics (Gunderson & Levine). The importance of number talk can also be seen in the classroom. Klibanoff et al. (2006) show that higher levels of math talk used by teachers in a preschool classroom is related to better development of basic math knowledge.

While it is clear that practices at home can have large impacts on the development of a child's ability, it is often an underutilized variable when it comes to mathematics. Gunderson and Levine (2011) establish that number talk at home is sparse, and while it does increase with time, it is well outpaced by talk of literacy. Compounding on the poor quantity, the language used is not always suited to a child's proficiency. Many parents do not accurately assess their child's math skills, often overrating their ability (Fluck, Linnell & Holgate, 2005). Furthermore, parents self-report that they are doubtful in their ability to teach early math concepts and skills (Cannon & Ginsburg, 2008). They state that they have uncertainty about their child's progression as well as when to advance their kids to more difficult concepts.

Anxiety towards the subject of mathematics is a contributing factor in the issues many parents have with implementing effective practices into their child's daily life. Anxiety towards the subject of mathematics is present in the United States and around the world and has been for some time (Foley et al., 2017; Hembree, 1990). Many college students report a degree of apprehension towards math (Beilock & Willingham, 2014). These anxieties often carry into adulthood. Children raised by parents with anxieties about math have been found to learn less when compared to children raised by parents with less anxiety (Berkowitz et al., 2015). On top of this, parents with anxiety towards math who attempt to help their children with homework can further deter their children, causing them to learn less math throughout the school year (Maloney et al., 2015). However, there is evidence that if support is provided to those experiencing anxiety toward math, the negative effects can be combatted. For example, in an intervention that asked parents to teach their children the importance of math, the parents' behavior changed. This changed behavior helped change the attitudes of both parent and child, which lead to improvement in educational outcomes 5 years post intervention (Rozek, Svoboda, Harackiewicz, Hulleman, & Hyde, 2017).

One pervasive tool utilized by parents in their children's math development is number and counting books. Traditional math number books aid in a child's math learning process by providing a format that encourages spontaneous focus on numerosity (Rathe et al., 2018). The key to this encouragement was the verbal aspect of the reading process. Rathe et al. also found that there is a positive association between focusing on numerosity during reading and the quantity of number-based talk throughout the day. One reason for this correlation is the act that exposure to storybooks is a predictor of vocabulary (Manolitsis, Georgiou, & Tiziraki, 2013; Martin-Chang & Gould, 2008).

Traditional Number books include features that promote both interaction and advancements in math ability. Ward et al. (2017) investigated the content of 120 counting books and found numerous trends across the sample. A majority of books contained repetition or rhyming phrases which helped keep children engaged. Most books contained no numbers above ten, listed numbers in ascending orders, and used real objects as their items.

Implementing a successful intervention that both promotes parent-child math talk and considers all existing literature can be difficult. However, electronic learning is an encouraging field that

offers possible solutions to integrating advantageous interventions. Numerous studies have been conducted around the efficacy of electronic learning. There is substantial interest in this topic due to the increase in the prevalence of electronic devices in both the home and schooling environments. Picton and Clark (2015) report that 97 percent of children have electronic devices as well as an internet connection available to them in their homes. This access spans socioeconomic status, race, gender and age (Pew Research Group, 2019). Additionally, children claim that they are more inclined to read on devices such as tablets, computers and phones (Picton & Clark). There is further evidence that children may be intrinsically motivated to use electronic devices (Guthrie & Richardson, 1995; Talley, Lance, & Lee, 1997) using them for upwards of 7 hours a day from the ages 8 and 18 (Hicks, 2019). When electronic devices were present, Trepanier-Street, Hong and Bauer (2001) concluded that children showed more interest in cognitive development tasks such as drawing, observing that drawings were more precise on computers.

Vernadakis et al. (2005) affirm the use of electronic learning for children finding that children who utilized technology have larger gains in intelligence, knowledge base, problem solving and language skills when compared to children who did not utilize technology. However, differing implementations of technology can result in varying rates of success. Buckleitner (2006) explains that computer interventions that are highly computer directed are not as beneficial as interventions that are directed by a person. In his study, when the technology offered insistent direction and praise, children performed less tasks and answered fewer problems correctly. When the children directed the tasks, they appeared more intrinsically motivated, and had greater success with the questions asked. Additionally, there is preliminary evidence that suggest electronic interventions aid in reducing the negative interaction between parents' anxieties and their children (Schaeffer et al., 2018).

Despite there being more than 80,000 educational apps available, hardly any of them have been vetted for their agreement with current empirical data on math learning (Hirsh-Pasek et al., 2015). Though unvetted, there are numerous advantages electronic platforms have over traditional books. Electronic platforms can contain all of the features found in traditional number books as presented by Ward et al. (2017). In addition to this, and eBook would have the ability to adapt to the individual needs of a child. This means the book would keep children in their zone of proximal development, not challenging them so much that they stall in their progress but challenging them enough to help them advance. Since the eBook would automatically adapt to the child's skill level, parents would no longer need to guess when to advance their children to more advanced topics. Removing the guesswork from the parents and providing them a structured method of communicating mathematical topics could aid in negating the adverse effects of parental anxiety on children's math development.

Everything considered, there is ample evidence that suggests the study and development of math skills is important, not only in academic settings but careers as well. Two important contributors to the growth of math skills are executive function and math talk in parents. Unfortunately, the attempts to capitalize on these two contributors are minimal. In an attempt to utilize children's fascination in electronic mediums, the developing of an adaptive eBook may increase the time children spend with mathematics and the amount of math language their parents use around them. Since very few of the existing electronic interventions have been tested for their both developing and evaluating electronic math books is vital.

## Acknowledgements

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